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Study program: N2301 – Mechanical engineering

Specialization: Engineering innovation

Focus: Product innovation

Department: Design of Machine Elements & Mechanism

„Design of Equipment for Assembly of HVAC-unit Air Canal"

„Návrh zařízení pro montáž vzduchového kanálu klimatizace"

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<u>Scope of work and attachments</u>

Number of pages:	82
Number of pictures:	37
Number of annexes:	11
Number of drawings:	5
Number of graphs:	3
Number of tables:	9

Date: 30. September 2014

TECHNICKÁ UNIVERZITA V LIBERCI

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ZADÁNÍ DIPLOMOVÉ PRÁCE

Jméno a příjmení	Bc. Souhayl El HAJJAM
Studijní program	N2301 – Stojní inženýrství
Obor	3909T010 – Inovační inženýrství
Zaměření	Inovace výrobku

Ve smyslu zákona č. 111/1998 Sb. o vysokých školách se Vám určuje diplomová práce na téma:

„Návrh zařízení pro montáž vzduchového kanálu klimatizace“

Inovujte pracovní stanici pro montáž vyduchového kanálu klimatizace tak, aby došlo k zvýšení productivity, minimálně o 25 % a snížení ergonomické zátěže operátora. Snížení takt-time o 20 %. Automatizovat šroubování na montážní pozici, operátor zakládá a vyjímá smontované díly.

Zásady pro vypracování:

1. Rozbor řešené problematiky.
2. Inovační příležitosti a definování cíle projektu.
3. Stanovení technických specifikací metodou QFD.
4. Návrhy min. 3 konceptů řešení a systematický výběr finálního konceptu.
5. Architektura zařízení a konstrukční řešení komponent, podsestav i zařízení.
6. Revize návrhu pomocí metody FMEA – K.
7. Závěrečné a ekonomické zhodnocení návrhu.

Forma zpracování diplomové práce:

průvodní zpráva: cca 60 stran analytická a projektová část práce + přílohy dle potřeby

Seznam literatury (uveďte doporučenou odbornou literaturu):

[1] Ševčík, L. a kol.: PLM systém a principy návrhu výrobku. Technická univerzita v Liberci, Liberec. 2010, ISBN 978-80-7372-641-6

[2] Mašín, I.: Inovační inženýrství. Technická univerzita v Liberci, Liberec. 2012, ISBN 978-7372-852-6

[3] Mašín I. & Jirman P.: Metody systematické kreativity. Technická universita v Liberci, Liberec 2012, ISBN 978-80-7372-853-3

[4] Ulrich, K. T. – Eppinger, S. D.: Product Design and Develpment. McGraw-Hill/Irwin., New York. 2004, ISBN-13: 978-0073404776.

[5] Analýza možných vad a jejich důsledků (FMEA). Česká společnost pro jakost, Praha. 1993, ISBN 80-. 020-0968-1. 6.

Webové stránky:

[1] www.behrgroup.com

[2] www.festo.com

[3] www.mahle.com

Vedoucí diplomové práce: doc. Dr. Ing. Ivan Mašín – KST FS TUL

Konzultant diplomové práce: Ing. Hanuš Jurenka – Behr, Mnichovo Hradiště

L.S.

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V Liberci, 29. Září 2014

……..…………………..

Bc. Souhayl EL HAJJAM

Thanks

- First, I would like to address my thanks to **Mr. doc. Dr. Ing. Ivan Masin**, for the time spent working with me to improve the thesis and he's great cooperation.
- Second, person I would like to thank is **Mr. Eng. Jurenka for support**
- Thirth, I would like to say that my master thesis is a gift to my parents and family one by one, which without them I won't be able to reach what I am having now. Special thank to: **Ms. Mgr. Rabia Bouhcine, Mr. Mgr. Lahcen El Hajjam, Ms. MUDr. Imane El Hajjam and Ms. Ing. Maroua El Hajjam**. Support of those people is inforgatable and I won't forget it all my life.
- An important person in my life which I would like to thank is **Mr. Jean-Marie Isoard.** This person is one of closed to my heart and very happy to know him.
- Unfortunately I can't bring all people and support one by one even if I would like to. This why I send a special thanks for any finger supported somehow.
- The last thing is a big thank for the **Czech Republic** and **TUL** for all conditions provide to make me a graduated from a county of EU. Without the support of all concerned I won't reach this. This support is also inforgatable and I will be grateful all my life.

evropský sociální fond v ČR

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OP Vzdělávání pro konkurenceschopnost

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Vznik tohoto materiálu byl podpořen v rámci projektu OP VK (CZ 1.07/2.2.00/07.0291) „In-TECH 2“

spolufinancovaného Evropským sociálním fondem a státním rozpočtem ČR.

Realizace projektu: 200 –2012.

Partneři projektu: Technická univerzita v Liberci - Škoda Auto a.s. - Denso MCZ s.r.o.

Manažer projektu: Doc. Dr. Ing. Ivan Mašín.

In-TECH2

ANOTACE

DIPLOMOVÁ PRÁCE TÉMA:

„Návrh zařízení pro montáž vzduchového kanálu klimatizace"

ANOTACE:

Diplomová práce se zabývá inovací zařízení pro montáž vzduchového kanálu klimatizace na výrobní lince Mercedes - Benz. Cílem práce je vypracovat konstrukční návrh za použití metod inovačního inženýrství. Z navržených konceptů vybrat nejlepší návrh a ten dále podrobně rozpracovat a optimalizovat. Výsledkem implementace navrženého zařízení má být zlepšení stávajícího procesu montáže z pohledu snížení pracnosti a zvýšení produktivity operátora.

DIPLOMA PROJECT

THEME:

„ Design of Equipment for Assembly of HVAC-unit Air Canal "

ANNOTATION:

This project deals with the innovation of assembly tool for air canal of the HVAC unit produced on the Mercedes-Benzs line of production. The main goal of the thesis is to provide construction concepts by implementing the methods of Innovation Engineering. The best concept from the suggested ones has been chosen, elaborated in detail and optimized. The whole process was conducted according to the basic principles of innovative methods. The results of the most suitable proposals will be presented and also defended. This concept will be implemented to improve the working position from the position of decreasing the intensity and increasing the capacity.

Key words: Innovation, QFD, FMEA, automatization, process, product, screw

The processor: TU v Liberci, Mechanical faculty, Design of Machine Elements & Mechanism

Finished: 2014

Archivní označení zprávy:

Table of Contents

List of abbreviations and symbols

Shorts	& Titles
QFD	Qualitty function depeloyment
FMEA	Failure mode element analyze
HVAC	Heating ventilation air conditioning
ppm	Part per million
BCZ	Behr czech republic
BPS	Behr production system
TPM	Total production maitenance
MKP	Method of fanalize elements
JIT	Just in time
ISO	International standard organization
VDA	Verband der automobilindustrie
MSP	Microsoft project
DP	Diplome thesis (Diplomová práce)
3D	3 dimensions
mm	Milimetr
m/s	Meter/ second
M	Moment
Mk	Torque moment
s	Second
MPa	Mega-pascal
D	Average
F	Force
Kg	Kilograme
ot/min	Rotation/munits
Nm	Neuton/meter
N	Neuton
pcs	Pieces
dB	deci-belle
EUR / CZK	Euro / Czech Koroun
Fig. / Tab./ Gra./ No.	Figure / Table / Graph / Number
%	Percent
ect	Et cetera
PPAP	Production part approval process

1. Company performance and products

1.1. BEHR Group

BEHR Group is one of the leading manufacturers and suppliers of original equipment for passenger cars and trucks. The headquarters BEHR GmbH & Co KG is located in Stuttgart. BEHR is a systems partner of the international automotive industry. He specializes in automotive air conditioning and engine cooling systems. Group sales in 2012 amounted to around EUR 3.7 billion. Currently BEHR employs approximately 17,000 employees in 38 manufacturing plants and 5 regionals R&D centers around the world. Countries where Behr operates are shown in the following figure (Fig. 1).

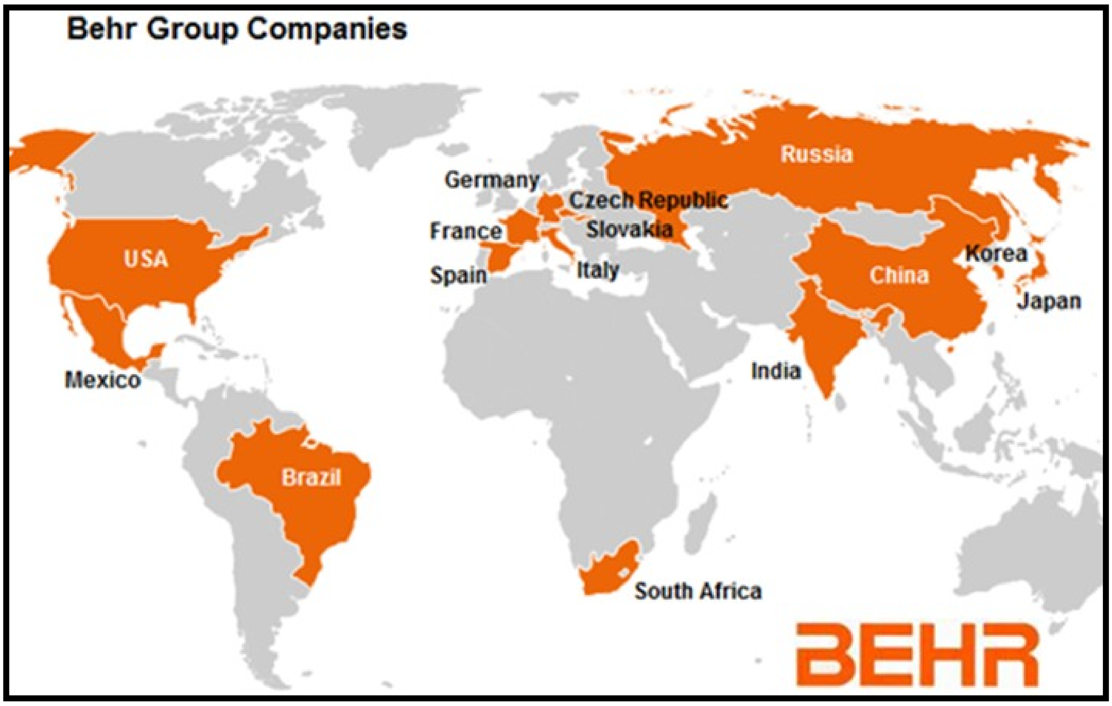


Fig. 1 Map races and company logo [1]

1.2. Integration to MAHLE

Since 2010 began the gradual integration BEHR - MAHLE. MAHLE Group acquired 51% stake in BEHR Group and it means that the property is transferred from BEHR to MAHLE. MAHLE Group is a world leader in air filters and engine components. Behr has become the third "bussines unit" by MAHLE. The result of merger of the two leaders of the future should bring better market value and better cooperation in the development and manufacture of products offered. Since October 2013 there has been a formal integration BEHR Group to MAHLE Group. After a completion of integration, was officially renaming to company MAHLE Behr.

BEHR Group has several production plants in Europe and outside Europe. One of the most important production plants is BEHR Czech s.r.o. Located in “Mnichovo Hradište”. This plant location is an important source of income and turnover increasing for the group in Europe.

BEHR Czech s.r.o. "BCZ" was founded in 2002 with a production area of about 38.000 m^2. BCZ Manufacture the engine cooling modules, HVAC modules and heat exchangers. Revenues in 2012 were about 268.4 Million EUR; wich is around 6710 million czk. The main customers are: Mercedes-Benz, Porsche, John Deere, VW, Audi, Skoda, Seat, Peugeot, Iveco, Mini-Cooper, BMW, Citroën, Volvo, MAN and of course others. BCZ is one of the fastest growing companies in the Group, particularly due to the application of BEHR culture and values (Fig. 2).

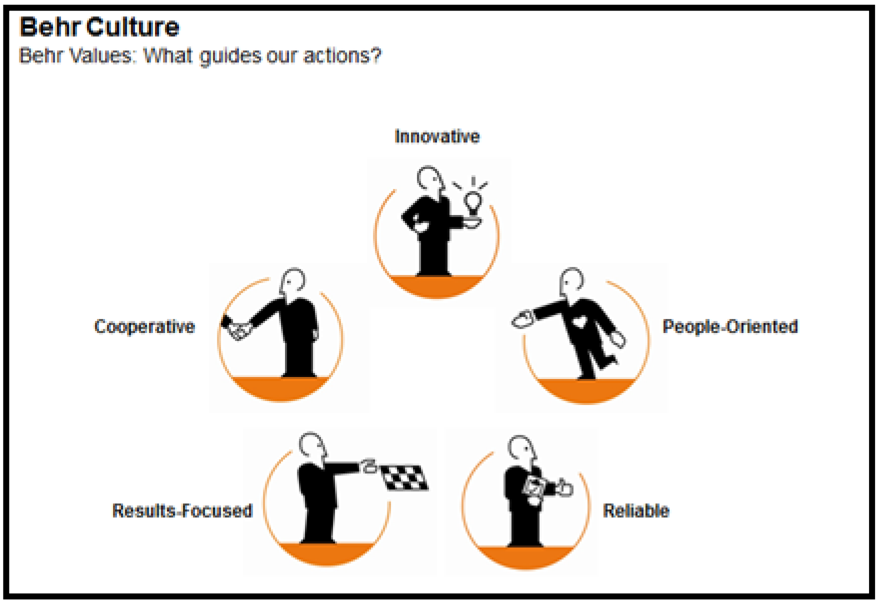


Fig. 2 BEHR Values [2]

The main activities of Behr group, as already mentioned, is the production of automotive air conditioning and engine cooling systems for cars and trucks. Such air conditioning system is shown in (Fig. 3).

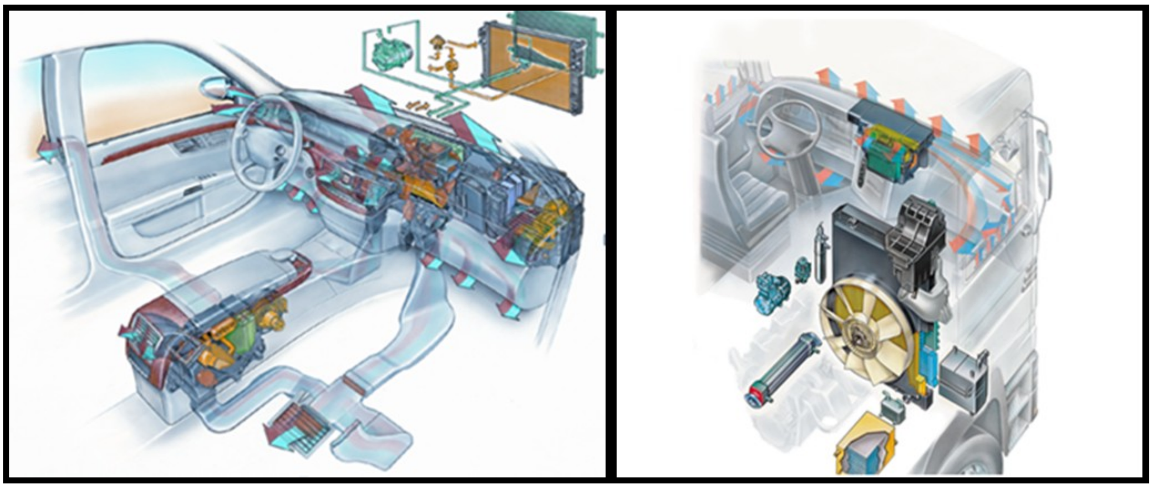


Fig. 3 Cooling system of thermoregulation of passenger cars (left) and truck (right) [3]

1.3. Air conditioning function

Basic functions of the air conditioning system are:

- Element of car passive safety - the fulfillment of this function is conditional on the system (especially running motor of car engines which are running by using START-STOP. Circuit cooling tends to have its own electric coolant pump which is called “Tray cold”). By creating optimal conditions for the driver (and passengers’ aswell) are delayed driver fatigue and thus the driver's ability to concentrate on driving and response to changing traffic conditions.
- Create a comfortable climate cabine vehicle.
- Depending on the vehicle cooling circuit, the electrical circuit of the vehicle on circulation systems and air purification.

Distribution of air conditioners:

- Manual: You can control the mixing ratio of air cold / warm climate vents units are usually only for the front seats.
- Automatic: You can adjust the discharge of air temperature, often for several zones (driver, passenger, passengers in the rear seats).

Description of function:

Air condition unit (HVAC) consists of the following components: temperature with air flow, ventilator, system valves, clapes and outlets, control with managing of air conditioning unit and air conditioning control panel. Basic circulation of air in air is shown in (Fig. 4)

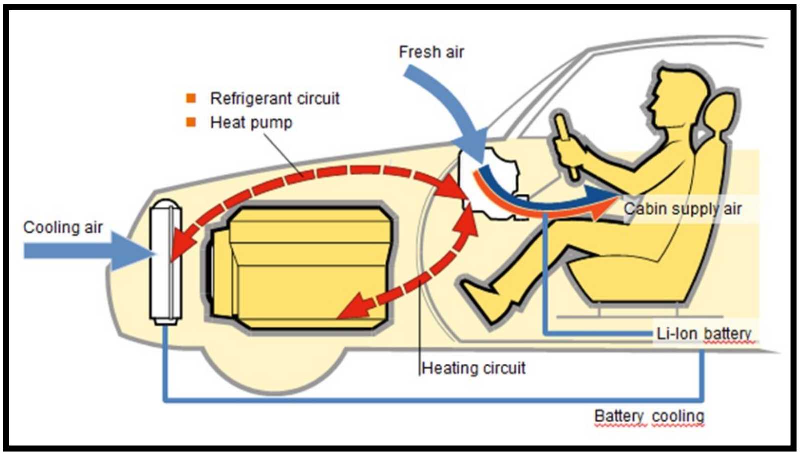


Fig. 4 Function of air conditioning in the car [4]

For air heating is used waste heat from the engine. Heater cores HVAC is connected to the cooling circuit of the motor (Fig. 5). BEHR climate units have a heater core connected all the time, only the output of warm air is regulated by air conditioning unit before the mixing at claps. If shortly after the engine coolant is still cold, the air vents especially for heated windscreen use PTC element - a ceramic heater (Eng. RAPID WARM-UP).

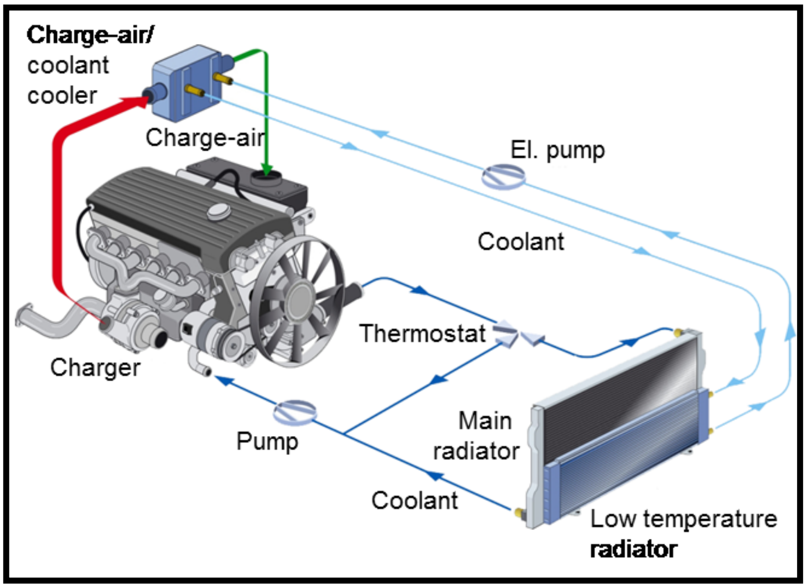


Fig. 5 Engine cooling functions [5]

For air cooling is used the air conditioner cooling circuit. This forms a capacitor with high and low-pressure piping, a compressor, evaporator and expansion valve. The cooling medium is a mixture of Freon and oil, or without Freon refill mixture of hydrogen fluoride and lubricating oil for the compressor. The Automotive coolants are usually labeled as R134a - a Freon R744 for hydrofluoric mixtures especially for CO_2 technology. Honneywell are pushing for a third kind of media - without fluoride. The mixture is explosive but unfortunately did not comply with the stringent European and American conditions of vehicles use; it threatens the passengers and the vehicle's surroundings.

When you turn on the air conditioner, the air conditioning unit evaluates the inlet air temperature, air velocity and temperature unit in the cabine. If the interior of the vehicle needed to achieve a lower temperature, the control unit activates the compressor. This increases the pressure in the high part of the cooling refrigerant circuit (condenser and expansion valve). Fluid under pressure passes through the dryer where they are separated traces of atmospheric moisture and solid particles produced by wear of the compressor and the small leak in the system. The medium then enters the condenser where it changes its state from liquid to gas (gives off heat caused by the compression of gaseous media before the compressor) and it's further pushing the expansion valve. In the expansion valve is the control unit for achieving the necessary pressure released valve needle and the medium is sprayed under pressure into the evaporator. Change of state is accompanied by a significant drop in temperature. Input air flowing through the evaporator in the air conditioning unit gives its heat to the evaporator as cold continues in climate chambers units before mixing air dampers. The sensor then signals the air temperature control unit and the air mixing damper adjusts so that exhalation into the vehicle and the vehicle to maintain the desired temperature.

1.4. BEHR Products

BEHR group operates in two divisions, which are: *air conditioning* or *HVAC systems* and *engine cooling Engine cooling*. HVAC is focused on heating and cooling that passengers adjusted according to weather conditions and according to their needs inside the car. Engine cooling unit operates largely in parallel with the motor. Goal is to cool the engine, to avoid all the problems associated with high engine temperature, which got arises during the operation. Individual parts of the air intended for the crew is shown in (Fig. 6 & 7). Illustrating the air conditioning components used for engine cooling.

Air conditioning products are:

- Air conditioning (HVAC).
- Evaporator.
- Heater core.

Fig. 6 Example of HVAC module, Evaporator and heater-core [6]

Engine cooling products are:

- Coolers.
- Radiator.
- Condenser.
- Oil cooler.

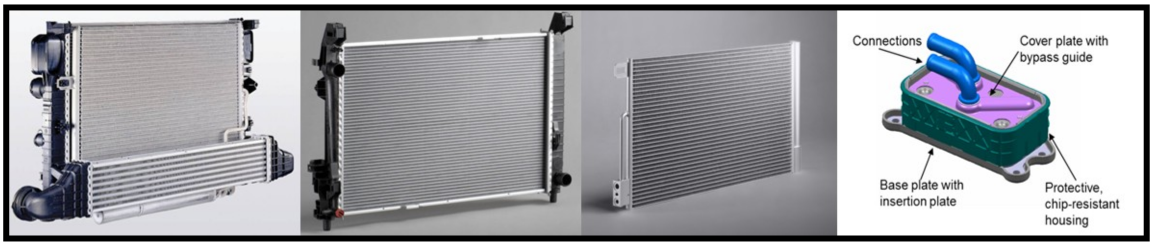


Fig. 7 Air cooler, radiator, condenser, oil cooler [7]

1.5. BEHR Group sales

Sales departments of BEHR groups are found in many areas, such as Europe, Asia, Nafta (USA, Canada), middle-east and others. Figure 8 shows the percentage distribution of exposure in the different countries.

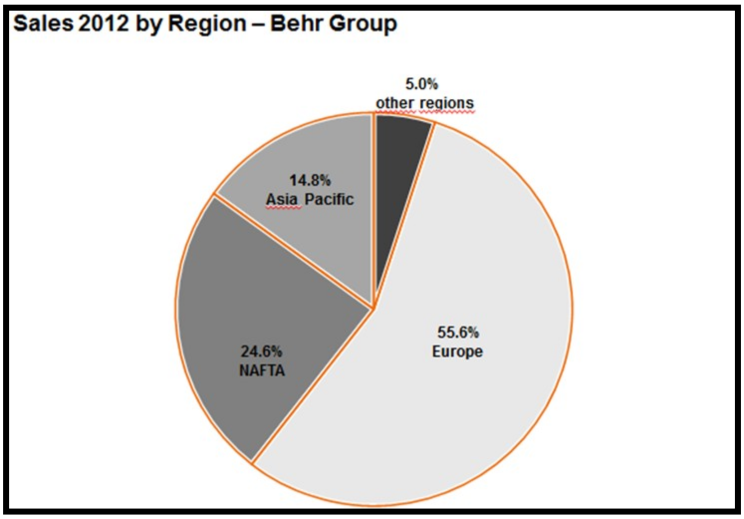


Fig. 8 Regions Group Sales BEHR group in 2012 [8]

1.6. BEHR production system (BPS)

BPS (Behr Production System) is an internal tool to monitors productivity. The main visions of BPS are:

- Zero scrap.
- Zero ppm.
- One piece flow.
- Just in Time.

Those goals present an ideal base status and thinking in a group BEHR with regard to standardization. It also focuses on innovation development of processes and organizational development of whole the company. All of these procedures are designed to improve company competitiveness.

BPS strategies are:

- High focus on customer value.
- Process orientation.
- Waste elimination.
- High standardization.
- Short production time.
- High work ethic.

1.7. House of quality principes

BEHR uses very important steps of structure to achieve the best goals on the market and competitiveness increasement (Fig. 9), for example:

- Just in Time (JIT).
- Failure-free production.
- Work organization and qualification.
- Total productive maintenance (TPM).
- Continuous improvement and problem solving.
- Visual management.
- Standardized flow and process planning.
- Technical planning and technology transfers.

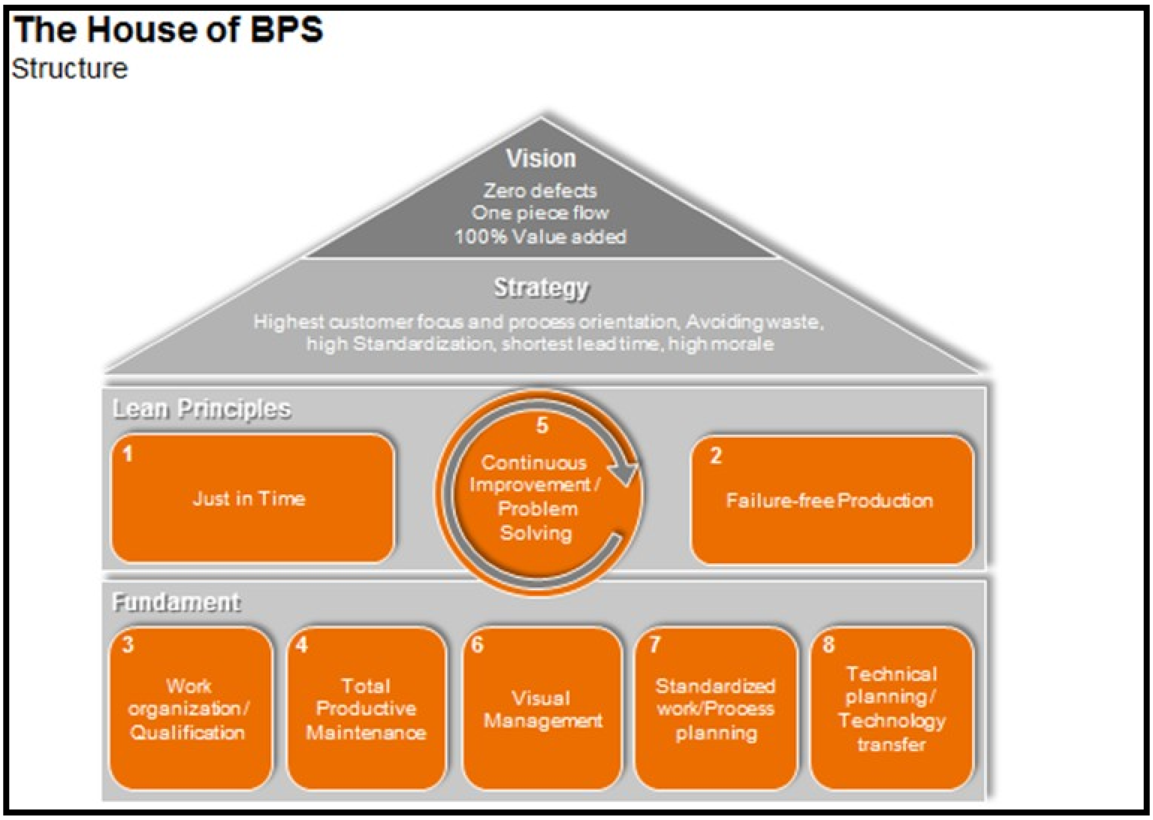


Fig. 9 House of quality of BPS to meet the vision and strategy [9]

1.8. Quality tools

Quality management is a very important element for BEHR and also within the group, without it we can’t reach fully functionalitty. Therefore, it is also necessary to require cooperation from both sides - customer and supplier. BEHR Group has all the ISO and VDA certificates to achieve all requirements in automotive industry from acquisition, development, procurement and production. These certificates are necessary for entry into the industrial market, so the company requires that all contractors and sub-contractors also possess these certificates. Without these contracts and certificates BEHR refuses any cooperation to prevent unwanted problems in the market with air conditioning (Fig. 10).

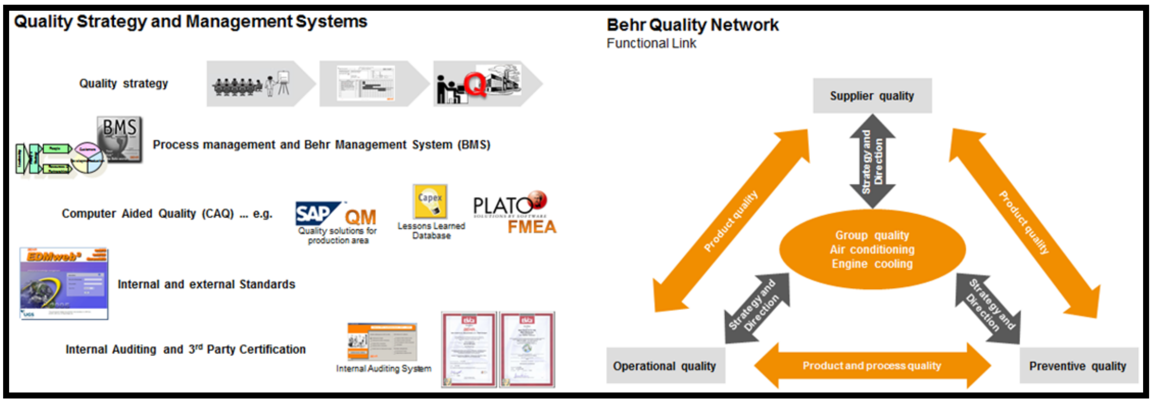


Fig. 10 Strategy of quality management [10]

Quality requirements are the basis for selection of contractor for a specific project. The required quality defect parts is *0 ppm* (part per million), which means zero failure rate accepted by the supplier on any component. We also demand a period of fifteen years from the completion of the project to ensure the supply of spare parts to ensure saturation of demand, even after ending the production.

2. Problem definition

The objective of this thesis is to find a suitable solution of the existing production Tool of concrete products which is in our case the “Air canal”. The main strategy of the company BEHR is to maintain its competitiveness in the market. That’s why we always focus on the cost savings in manufacturing time, which takes precedence over other economic saving processes or distribution of subjects. BEHR's management team believes that if automatization was implemented on all production sites, the production time would be reduced, thus this could have a positive impact on the internal volume production of products per shift, more precisely, per day.

The theme of this thesis has been suggested on the basis of practical experience inside of the company BEHR. My customer, BEHR, convinced me that the work can be beneficial for the development of society. One of my main interests is study this technical problem into a greater depth in order to improve my skills and knowledge in the fields of design, quality control and production time.

2.1. Current status

Device current status at production line is shown in (Fig. 11). Comprised from:

- Main frame (shown under reference no. 1).
- Manual rotary table (shown under reference no. 2).
- Manual hand screw-driver.
- Vibrating screw feeder with suction channel.
- Hand lever to rotate the table.

More detailed information on the design of the machine in its current in appendix no. 3.

The picture no. 11 is showing the actual working tool used by operators to assembl parts for air canal manually. This simply means that the whole process assembly is manual from part fixiation of parts to holding table followed by the screwing and finishing by putting the product in to right box for next step of delivery. Global view of tool is shown below.

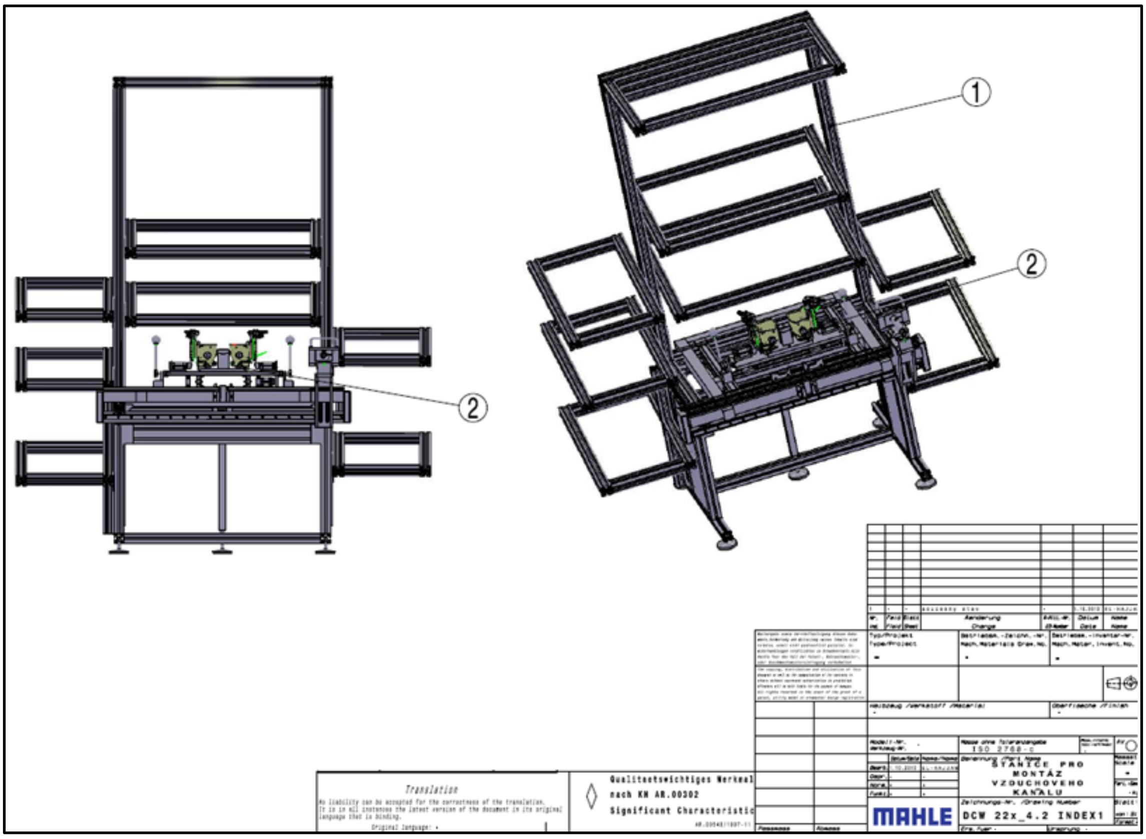


Fig. 11 The current status of the machine [11]

The following figure shows an assembly station of air canal (Fig. 12), for which I will introduce a new design innovation. Figure demonstrates screw-driver which is present in the process used for manually processing of the twelve screws with two air channels. Photographs display several workstations plastic washers (multipacks) on which the products components are supplied such as stepper motor, claps and so on. Yellow suction air tube is also shown, it helps to lead the screws to the head of screw-driver, a suction channel is connected to the vibrating feeder screws and it’s used to connect the screws to the head screw-driver without operator assistance. This is a standard procedure; the innovation is not subject of the present thesis.

Other working steps on this station are currently fully manual. The aim of this thesis is to upgrade these procedures, so as to shorten production time to the extent that budget allows investment and access to technology in the market.

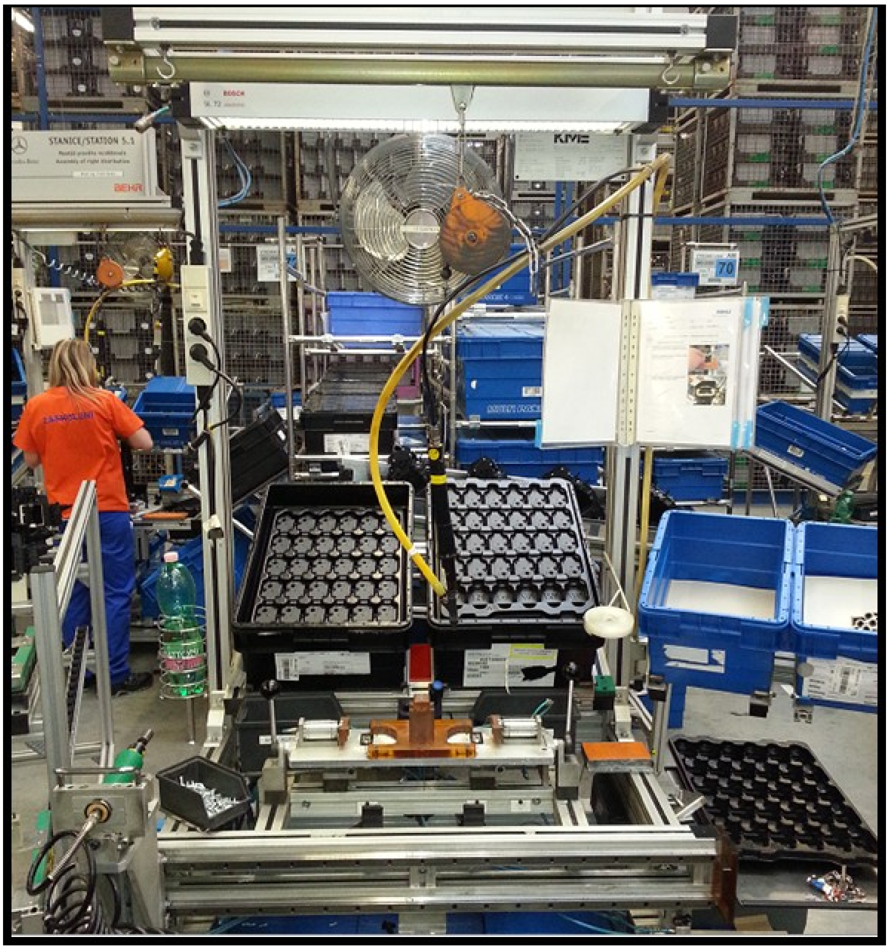


Fig. 12 Existing assembly station [12]

Production facilities are located on site number 4.2 Line manufactures air conditioning for Mercedes-Benz, DC W22X platform. A detail line is shown below. The workplace is highlighted in red frame (Fig. 13).

Material flow is shown on the layout below. The work station number 4.2, which is releated to my thesis, is the first working station for assembling and completing the air canal, other steps follow to complete the whole HVAC product. To see the material flow please take look to red frame on the picture 13, it's shown with shapes.

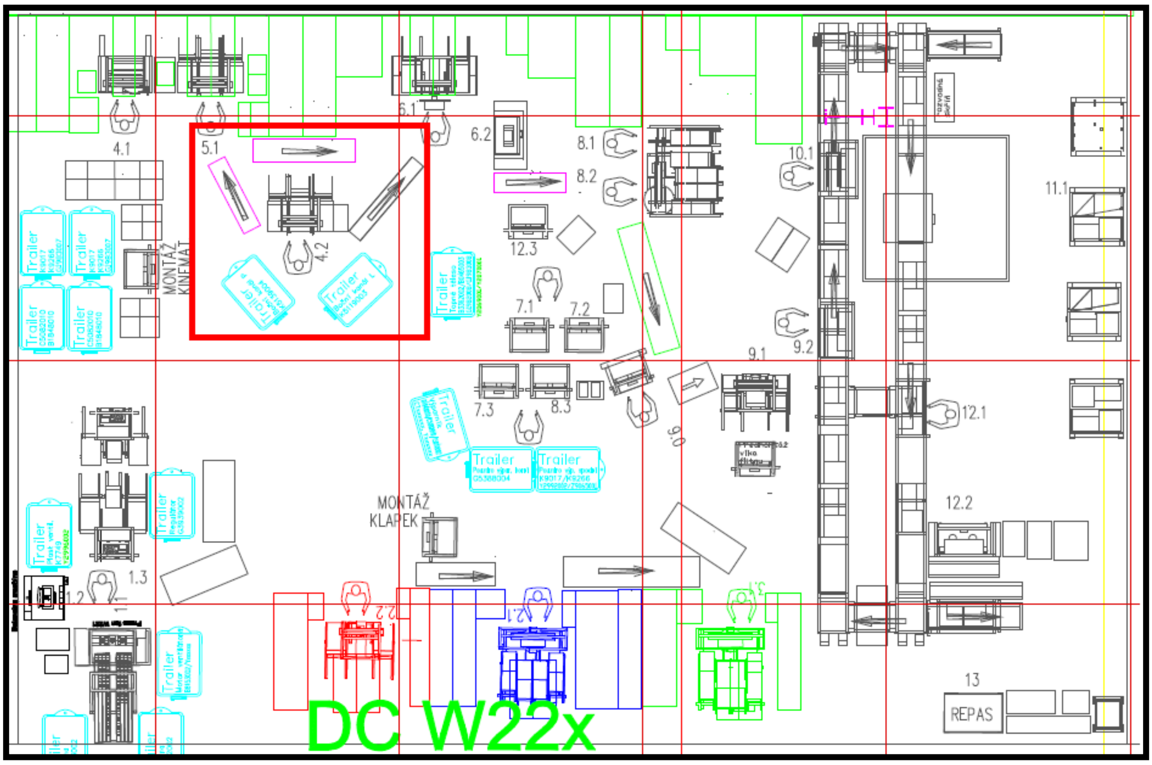


Fig. 13 Layout lines Mercedes - Benz [13]

2.2. Production function

The product is composed of five basic parts:

- Air canal (left and right air canal).
- Clapes (4 valves clapes).
- Carrier (4 carriers).
- Screws (12 screws).
- Stepper motors (4 stepper motors).

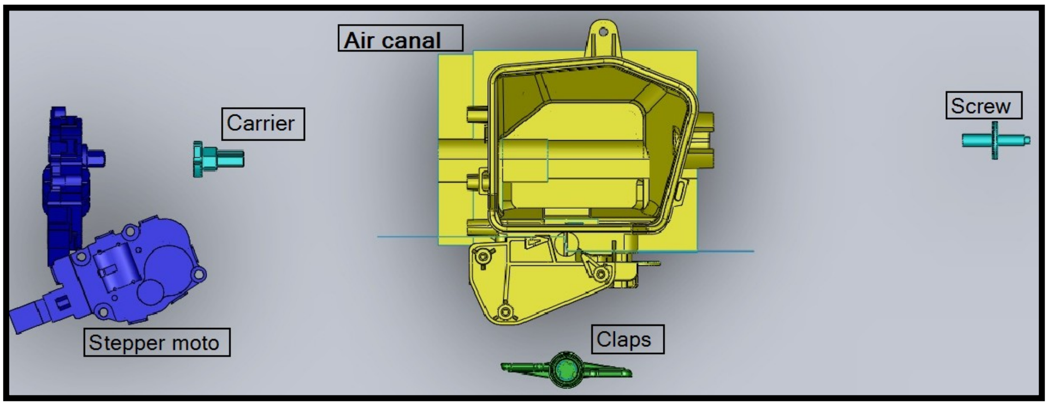


Fig. 14 Product with parts [14]

The task is the assembly of the air conditioning canal in the control flow of air to the air conditioner according to the settings in the passenger cabin of the vehicle. While driving, passenger car may, at its current needs, regulate the access of air to the cabin crew with the help of the air conditioner control panel. The control panel is in the case of a manual air conditioner connected with the dampers in the air canal to bowden cable. In our case, for automatic air conditioning is using stepper motors. Control panel controls the air flow in air conditioning settings according to the respective flapss (Fig. 14).

2.3. Charachterestics of current tool

Features of the current machines are:

- Ergonomic workplace standing, 800 x 800 mm, electrically adjustable in height, including storage areas.
- Swivel mounting and fastening with shaped clamps for clamping the left and right channel side jets.
- Horizontal linear guidance system for correct positioning of the double screwing a screw with a screw-driver air, adjustable for right-and left-hand version, including stops and checks.
- Container materials supplied to BEHR.
- Andon.
- Workplace lighting.
- Shelves.
- Mounting for lighting, screw-driver etc.

Arranging your work is done by the contractor before releasing the design. It is, however, necessary to agree with Behr. Attaching the control panel is handled separately. Mechanically machined parts are surface treated.

The check is performed as Poka Yoke, the key specifications of the torque and the number of bolts. Other parts are attracting screw-driver with screws (not part of the menu) and balanced included in the scope of delivery.

2.4. Description of existing workflow:

I will try to explain how air canal assembly machine works (Fig. 15).

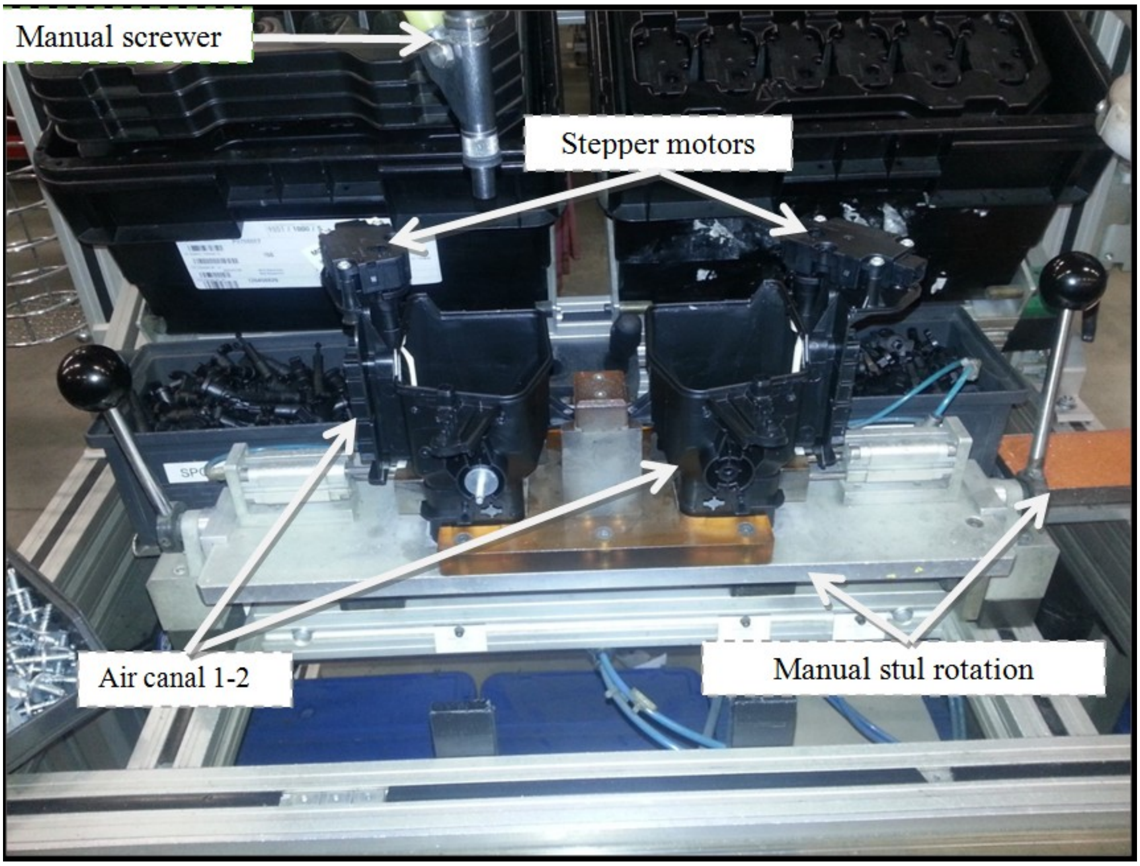


Fig. 15 Air channels with stepper motors and screw-driver [15]

Figure 16 shows the setting of the air canals in both positions. The initial position of the established channels is vertical. With the manual lever, the entire table, including the channel, is rotated 90° to the channels and comes into the horizontal position and exposes additional screws needed for connecting channels in the whole.

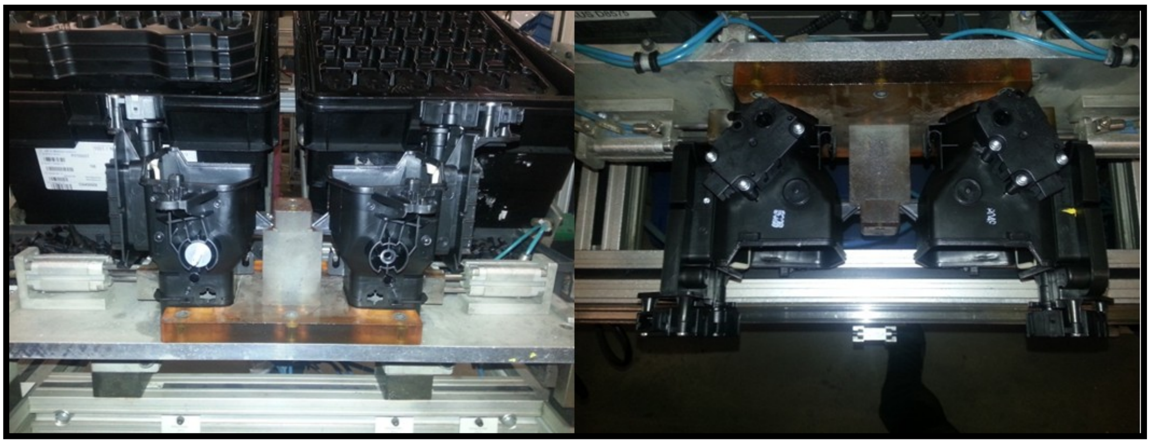


Fig. 16 Front view of the working table rotation [16]

Tools to build stepper motor with left and right channels air HVAC is constructed of:

- Left and right air canal.
- Four deicing flaps.
- Four carriers.
- Four stepper motors.
- Twelve screws.

The operation is carried out following the installation procedure, which is divided into two major steps. This means each main step includes several sub-steps. The first major step is the manual assembly of parts of the right and left air canal. The second major step is manual screwing stepper motors in frame air canal.

The first major step "*Manual installation*":

1. First grasp the left respectively right air channel.
2. Second mount 2 x defrost flap to the left or right channel.
3. Third take 2 carriers and insert it into both deicing valves.
4. Fourth to take two stepper motors and settle to carriers.

The second major step "*Manual screwing*":

5. First using a screw-driver to put compressed air to each stepper motor 3 screws.
6. Second to turn the assembly plant by 90 ° towards the front using the hand lever.
7. Third turn mounting table of product back into the initial position.
8. Fourth remove the left and right channels of the product and postpone the

preparatory transport box.

2.5. Distribution workstation

If the workstation is divided into two separate parts, then we can define the following simple device structure (Fig. 17).

According to the simplified diagram station with the product in Figure 17, we see that the workstation consists of three basic parts (holder of the product, screw system and product it self).

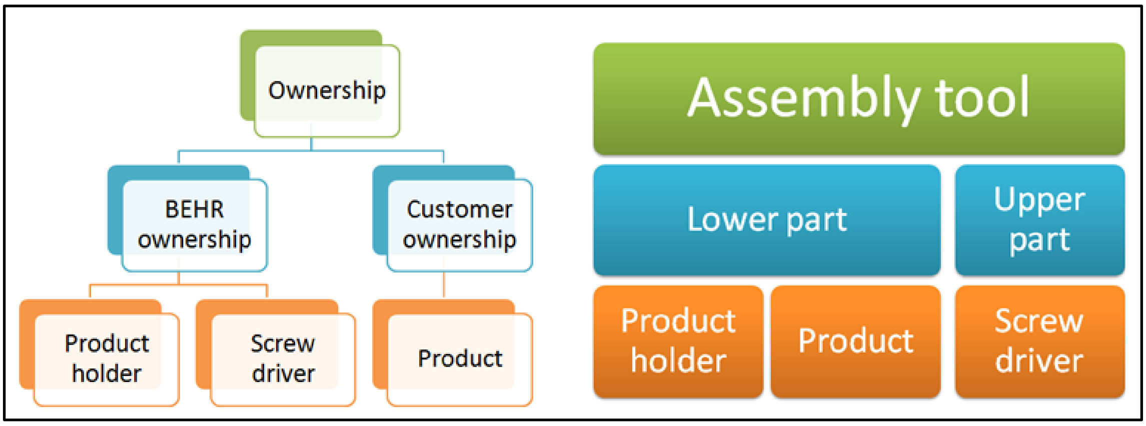


Fig. 17 Simplified diagram of a workstation [17]

The upper part of the device consists of a hand screw-driver only. The lower part can be divided into two main sub-groups, which are holder of the product and the processed product. Complete assembly station is owned by BEHR. Therefore, it will be possible to design innovation and product holders to screw the system without demanding administrative and approval processes, and thus will guarantee any quick implementation. The product is defined by the customer in the acquisition phase, with which the customer agrees in advance and any change of this product is subject to the consent of the customer. A significant intervention into the construction of the plastic parts of the product in mass production phase is eliminated primarily due to:

- Required customer awareness and acceptance of any modifications to the product or product specifications, leading to the approval of the audit.
- The impact of product modifications to production equipment, those are modification of the product, you will need to reconfigure the device.
- Influence components of the assembly of the air duct, which is part of the air

conditioner. This means that any potential change may bring another change of parts in an assembly conditioning.

- The cost of a new injection tools in case of modification of the air duct, as well as other parts.

2.6. Why we use the screwing operation

After analysis of how the product look like, there may be a question "*it is necessary to screw*?". The process of screwing it should be used in the following cases:

- Customer request - this is an operation requested by the customer according to supplied specifications of the product.
- Easy assembly and disassembly of stepper motors for HVAC, the customer is testing the air conditioning unit operating for 3000 to 5000 hours, testing is performed without stopping (non-stop of air conditioning).
- Greater flexibility and reliability.
- Lower price.
- Shorter cycle time for an operation.

2.7. Consumption measurement work

First of all I would like to explain how I got the results used on the table no. 1. Results used in table are from the methods of time measurement (MTM). Method used to measure the time internally at the company BEHR. As this is not a topic for my thesis, so I will not go very deep in details such as how this method works, but I will just mention that the time results mentioned in the table are measured by specialist at company BEHR and its internal information.

Analysis of potential workplace (Tab. 1) shows the decay time-consuming individual parts of the operations carried out in the workplace. Fundamental data analysis for the present work it is time to hand screwing. The analysis work suggests that the current process time for all of these work activities is 77 seconds per pair. Labour intensity screwing is 36% of the total labor input in the workplace, which is an interesting potential for improving the process (Graph 1). By saving labor intensive manual screwing, the first station will reduce the labor intensity and so cost savings. The operator currently operates work stations (stations of the air canal, which will be modified).

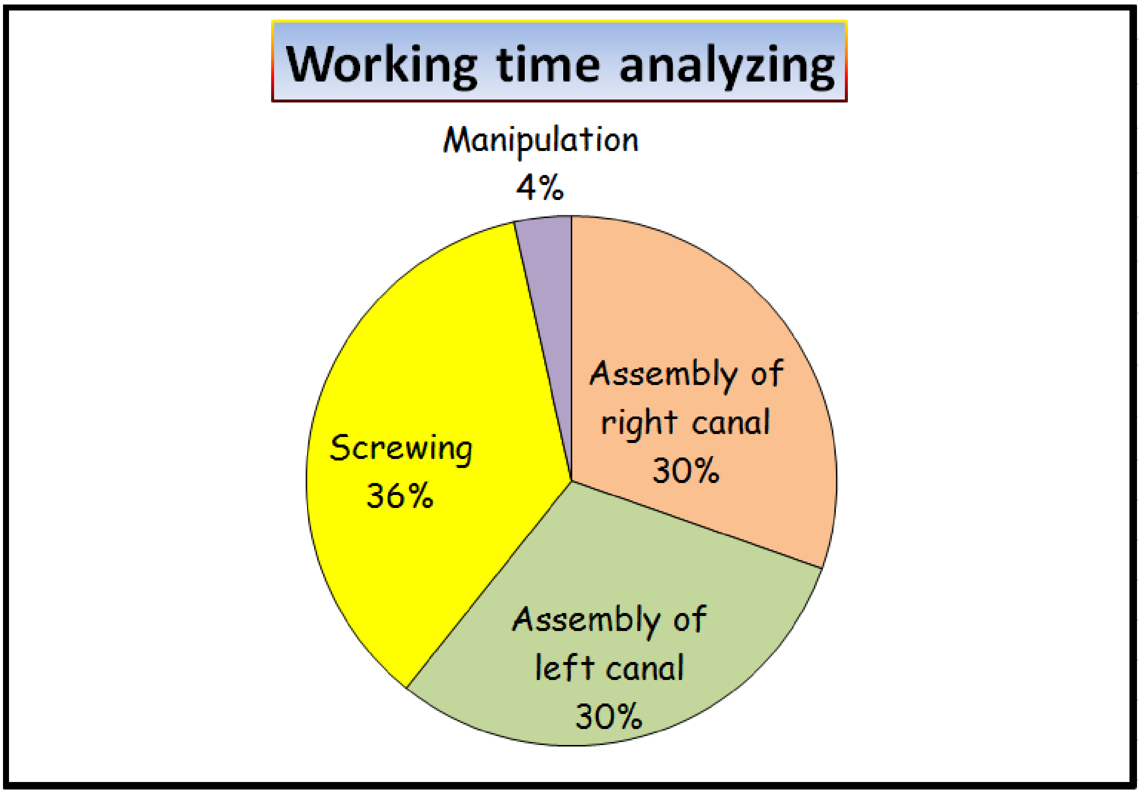
The requirement of company BEHR is to implement the new technologies at the market to reach a saving of production time and avoid time waste of manual screwing made by operator. If we can save this time of screwing I am very sure that we can use this new capacity of the operator for many other tasks. What the operator can do once we saved the screwing time is an open question until now, but I am pretty sure that a lot of tasks can be done. This anyway, should be discussed with process planning and line supervisor to see what are the priority needs up to date.

The idea of this thesis is to use new technologies (auto screwing) to the existing work flow of operator, then to implement automatic screwing so to automate the process of screwing. The goal of all of this is to save time and free the capacity of operator.

Project Automation screwing brings us major improvements in the form of creating the potential for realignment work operations within lines and better balancing lines.

Tab. 1 Time of individual work activities on a workstation by operator [1]

	Work instruction	Time [s]	Frequency	Total time [s]	Total time / Operation [s]
Left canal	Grasp left canal	1,74	1	1,74	23,5
	Assembly of flaps	2,83	2	5,66	
	Assembly of carriers	2,68	2	5,36	
	Assembly of stepper motors	3,98	2	7,96	
	Settle into transport table	2,78	1	2,78	
Right canal	Grasp right cana	1,74	1	1,74	23,5
	Assembly of flaps	2,83	2	5,66	
	Assembly of carrier	2,68	2	5,36	
	Assembly of stepper motors	3,98	2	7,96	
	Settle into transport table	2,78	1	2,78	
Screwing	Screwing screws for assembly	2,31	12	27,72	27,72
Manipulation	Total time needed for logistic	2,69	1	2,69	2,69
Total time needed		33,02		77,41	



Graph 1 Percentage of times spent by operator of individual operations [1]

We can see on the graph the following:

Manual assembly of right canal is presenting 30% of the time consumed, unfortunately this won't be a focus point of improvements. Because of the high cost in case we would like to automate the operation by using robots. This means that this operation will stay as it is.

Manual assembly of left canal. Exactly the same principe for the right one. It won't be a topic of focus as well for the same reason as right canal assembly.

The 4% time consumed by manipulation will remain the same, due to need of this operation. Also needed to explain that the packaging plus transport times are included to this activity which fits pretty well with the time measured.

Last thing to discuss is the screwing which is presenting a very important percentage time at the operation. This will be my focus, by avoiding the manual operation and using an auto-screwing to avoid the time wasted by operator and makes the operation much more reliable. Until today all is made manually, which means that we have a higher work of operator, less productivity, less precision, not sure that screws are screwed until the end and other issues will be mentioned last on the thises.

2.8. Planned budget

BEHR budget for this project can be calculated as follows:

- Consider a cost savings for one operator, estimated at 15,000, - € / year (estimated cost for operators in the country).
- Taking into account that the production work on 3 shifts / day. This means that we have available 15,000 x 3 = 45.000, - € / year.
- Estimated total cost in Czech crowns is therefore 1,200,000, - CZK.

The main evaluation criterion of the final solution is based on the high quality of the proposed facility, shortening work time (tact-time), operator safety equipment and reasonable prices.

The most critical parameter for deciding the investment in innovation intensity of the line is the price as the existing line is in operation for more than 10 years. This means any high investments in equipment are not appreciat or desirable by company.

The return on this investment should be optimally time within 2 year after the introduction of innovation in the process. The aim is not to exceed the cost of implementation over 45.000, - €.

Savings in the case of implementation in all manufacturing operations with the possibility of screwing in the event of success of the project and its devolves to other operations could bring very good savings for the entire company.

2.9. Advantages and disadvantages of the current state

Current state has several advantages and also disadvantages. Objective of innovation is always worked out do to improve or eliminate disadvantages. If you leave the current situation, we basically nothing improve. In the case of innovation, we will have benefits in terms of shorter production time and increase productivity, including higher reliability with over 30 percent free capacity of operator to use somewhere else. Thus, the company BEHR will be more competitive and can implement automatic screwing in all other lines of work, or even races around the world. In picture no. 18 are listed the advantages and disadvantages of the prior.

Advantages	Disadvantages
▪ No new training for operators ▪ Already existing documents for line production (FMEA, PCP, flow-chart) ▪ Flexible way of screwing ▪ Low cost maintenance, set up, energy and environment life time ▪ Low cost screwing system and spare parts ▪ Low noise	▪ Higher cycle time ▪ Low productivity ▪ Higher work of operator ▪ Impact of operator to development ▪ Safety ▪ Reliability of operator ▪ No diagnostic ▪ Higher vibration ▪ Low precision

Fig. 18 Advantages and disadvantages of the current state [18]

From the analysis of the current state I can confirm that I can work to improve the following points:

- Reduce the labor intensity of the machine operator.
- Increase the capacity and productivity of the machine.
- Increase security.
- Reduce machine cycle.
- Increase the reliability and accuracy.

More parameters will be defined after an internal meeting with the customer and the definition of functional requirements for QFD.

2.10. Innovative opportunities

Identified the following innovative opportunities:

- The equipment enables automated position adjustment screw-driver.
- The equipment has an automatic start screwing in achieving positions.
- The equipment has automatic feeding screws to the screw-driver.
- The equipment allows automatic positioning of the product during installation.
- The user has the possibility of rapid exchange of screwing tools.
- The user has the option to change the number of threaded bolts in one working cycle.
- Devices allow easy editing of parameters (speed, torque moment).
- The equipment will allow the creation of other programs.
- Automatic clamping device allows the product after its founding.

- Device checks the number of connecting bolts in the product.
- Device controls the right moment once all the screws are tight.
- Facility after completion of the operation allows automatic disconnection of the product.
- The equipment meets the ergonomics for the user (machine operation).
- Device itself monitors the amount of bolts in the tank.

2.11. Innovative plan

The goal of innovation is a change in the existing equipment used for the manufacture of subassemblies conditioning stepper motors, which allows automatic operations on the screw on the product, including its automatic clamping of the establishment and disconnection after the completion of screwing. The device also allows monitoring of quality parameters of the joints with torque and also monitors the presence of all the screws in the subassembly. Program management tools enable editing of process parameters in the user interface and eventually subroutine. Innovation should reduce production time (under the existing 77 s) and should fit into the budget of 45.000, - €.

2.12. Timetable

The timetable has been designed with the support of Microsoft Office Project, which is suitable for fast planning and monitoring of individual steps and items. Project thesis includes a number of steps for achieving the prescribed goals (Fig. 19). These goals are:

1. First, select a theme first DP, setting goals, their consultations.
2. Second, analysis of the topic, analysis of budget and description of the current state of the machine.
3. Third, QFD analysis (analysis of customer needs) according to the needs and market opportunities. This is the most time-consuming step. The reason is that the customer has mostly concrete idea about their requirements and puts them under a general requirement of "better product". Identifying specific customer needs and expectations requires repeated personal conduct.
4. Fourth, design solution, work in 3D modeling program designed for and adding new features.
5. Fifth, FMEA analysis, to make a sure about product quality monitoring and

assessment of the extent to which agrees with the required quality and needs.

6. Sixth, final assessment of the results of work according to the economic and technical aspects.

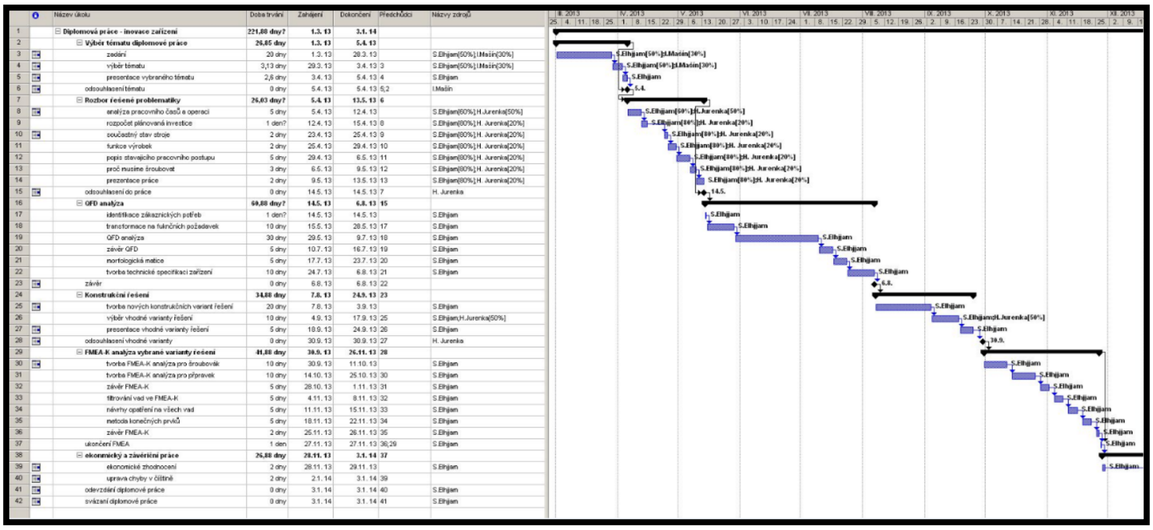


Fig. 19 Time table for the project [19]

3. House of quality (QFD)

QFD (Quality Function Deployment) method was developed in the firm Mitsubishi in the 70s of the last century. It is a tool of innovative engineering development phase. The method is designed to transfer the voice of the customer into technical language and thereby identify customer needs. After evaluation of customer need than we assign them to technical specification. QFD is based on teamwork across all departments of the company. Work on QFD was as follows these steps:

1. First, meeting internal customer (BEHR Group), which I lead a result of internal meetings to define its needs (Needs).
2. Second, I lead the person working in a team to transform customer needs into functional requirements or internal customer needs (Requirements).
3. Third, create a QFD house of quality according to functional needs.
4. Fourth, define output of QFD under technical specifications of the machine.
5. Fifth, subsequently create a morphological matrix for the selection of optimal solutions.

3.1. Identification of customer needs

Before talking about the customer needs, I would like to define who my customer is in this project. The customer for me is presented by my internal working colleagues of company BEHR, the people which are involved are: Project Manager (project management and responsibility of budget), Quality manager (define and control all quality parameters), Designer (discuss technical specification) and other team members. Those people were consulted during all my discussion about needs, requirements and tool specification. I was leading all meetings, but taking their opinions in consideration all the time of discussion. Always when I will refer to customer in my thesis, this means that I planned and manages a meeting with the right person conserned by topic, such as: Project leader, Quality manager or others.

During internal meetings in the company BEHR which I personally led, I asked the customer the following question "*what will be the future expectation about innovation of workstation station of air canal on the Mercedes-Benz line?*".

The answer was that during Innovation we must take in account of the needs mentioned below. Those are important for the client. The innovated tool must meet the following requirements:

- Higher productivity.
- Lighten the work of the operator.
- Better function.
- Better ergonomics.
- Greater safety.
- Easily adjustability.
- Use better method of screwing than the current manual.
- Shorter production time.
- Easy maintenance and adjustment.
- Easy handling for the operator.
- Shorter delivery time machines.
- Low power consumption.
- Aorrect screwing all the screws.
- Naturally low investment (return on investment within 1 year).

Of course the customer requirements are more than the mentioned once, but I used this for simplicity of work. More details will be mentioned in paragraph of functional requirements.

Following an internal meeting, I filtered according to customer needs according to five main parts, which are: Design, Function, Safety, Ergonomics and Price. Filtered requirements are listed in Tab. 2.

I would like to mention a very important point during discussion with customer which is the “Costs”. I should consider that the production line is already exisiting almost 10 years, this makes the innovation limited by defined budget. The management decided to don’t invest that much for already exisiting tool. During all discussion the budget was the most critical and important parameter to consider for nomination.

Tab. 2 Filtering customer needs [2]

Tool construction
Use of new technology
Figuer out what should be improved in the new tool
Easy construction
Make sure of functionality of screw-driver
Figuer out the screws assembly
Keep the maximum working steps
Keep same work flow
Don't change actual way of production
Eliminate consequences arising of construction
Easy spare part change
Keep same actual status
Tool functionality
Improve screwing tool
Screw in shorter time
Possibility to save working time
Safety
Savety of work
Possibility when ever to stop the tool
Egronomy
Tool location
Easy use of tool by operator
Price
Minimum financial cost
Use maximum of existing parts

3.2. Functional requirements

Customer needs has been interpreted and then transformed to functional requirements. This means that we transform everything what a customer wants to specific parameters. More details are in Tab. 3. In the table is describes the transformation of customer needs to functional requirements.

It's necessary to highlight an important remark during discussion with customer. During all discussion the customer used global words which are very hard to define, such as: better production, easy construction, easy work for operator and so on

Unfortunately the customer was not able to replay to my questions such as *"what do you mean with better production?"*. To solve this situation I tired to orient the customer to the maximum possible answers close to what we need, by keeping asking about the samething and even reformuling my questions to be be much more specific.

Table no. 3 shows the customer needs with interpretation and requirements.

Tab. 3 Transformation of customer needs to functional requirements [3]

Customer needs	Interpretation	Requirements
Higher productivity	Tool must produce more parts than existing	Higher number of parts by shift
		Low scrap
		Stable production process
		Eliminate tool stops
		Quick movement of screw-driver
Easy work for operator	Less work for operator	Automation selected activities by operator
	Reduce the physical stress operator	Reduce operator fatigue
Better fucntions	Improvement of existing features and enhancements screwin	Automatic screwing with pneumatic screwdriver
		Automatic screwing with electric screwdriver
		Automatic positioning screwdriver
		Automatic rotation fixture
Better tool ergonomie	Respect standardized ergonomic regulations	Application of prescribed rules to design machines
		Ergonomic position relative to the machine operator
		Adequate lighting work simplicity
		Avoiding high needs manpower for installation and operation of the machine
Higher safety	Tool must confirm the maximum safety for security	Sensors
		Photocell
		Avoiding sharp edges
		Low noise
		Stop button
		Grounding equipment
		Safety equipment
Easy adjustability, maintenance and adjustment	Machine must guarantee easy and quick adjustability	Quick and easy adjustment
		Easy maintenance
		Quick setup
		Easy release to production machines
		Easy machines cleaning
Short tool leadtime	Very short tool production time	Quick delivery of parts
		Quick tool time production
		Connection speed
		High speed of tool testing and release of production
Short production time	Shorten the cycle time required to produce 1 piece	Accelerate the process of screwing
		Acceleration rotation fixture
		Acceleration positioning screwdriver
		Faster feeder screws
		Acceleration clamping
Machinery precision	Machine must be accurate to complete their work	Choose the right speed
	Screwing the screw into the end	Precise tightening torque
	Screwing all screws without exception	Accuracy angle screwdriver
		Location to place the screwdriver screwing
		Screwdriver axis coincides with the axis hole Product
Warranty	Long term of warranty agreement	Have longer warranties
		Possibility of extending the warranty if necessary
		guaranteed lifetime component
Easy construction	Using all existing and only standard parts	Existing components from a catalog
		Easy replacement of parts
		Use existing parts of existing machines
Low price costs	Selection of the cheapest offer	Fit into the budget planned investment
		Controlled selection of the cheapest supplier
		Discount for purchase of spare parts

First I asked the customer to identify customer needs in order to obtain a clearer view of the future status of the machine. The answers to my question: *"What do you expect that a new machine to meet?"*, were summarized in the first column of Table 3. Then I will talk about each customer's needs and fantasies, I described exactly what was hiding under their needs. These explanations can be found in the second column of Table 3, entitled *"Interpretatino*" or we can also say explanation of customer needs.

The next joint meeting with the customer (which I led), I judged the customer requirements and I valued them. Afterword I requested from the customer to review it together to check if those parameters are acceptable or not. The customer confirmed that that paramerts are acceptable and we can go further with those results.

Requirements and values could be found in listed Tab. 4.

Tab. 4 Functional requirement for a product holder and screw-driver [4]

Functional requirements for Screw-driver	Value
Larger number of units produced per shift	5
Reduction of scrap	5
Maintaining process stability	3
Rapid shift screwdriver	6
Eliminate downtime	2
Reduce operator fatigue	4
Automatic screwing with pneumatic screwdriver	3
Automatic screwing with electric screwdriver	3
Accurate positioning of the screwdriver	10
Application of prescribed rules to design machines	1
Ergonomic position	7
Sufficient illumination of the work area	4
Low vibration equipment	2
Photocell	2
Low noise	1
Safety equipment	7
Grounding equipment	1
Quick and easy adjustment	6
Easy maintenance	4
Release to production machines	1
Life pointing device	4
Easy cleaning machines	1
Speed delivery of parts	5
Speed reconstruction device	3
Speed wiring devices	4
Speed testing machines and release to production	5
Acceleration positioning screwdriver	5
Faster feeder screws	5
Accurate speed	9
Precise tightening torque	9
Exact angle of the screw	9
Reliable feeder screws	4
Control of the torques	10
Check the number of screws screwed into the product	10
Tighten the terminal screws to the product	10
Have longer warranties	2
Possibility of extending the warranty if necessary	1
Guaranteed lifetime component	3
Existing components from a catalog	5
Easy replacement of parts	5
Fit into the budget planned investment	5

Functional requirements for product holder	Value
Larger number of units produced per shift	5
Reduction of scrap	5
Maintaining process stability	3
Eliminate downtime	2
Automation of rotation	10
Application of prescribed rules to design machines	1
Ergonomic position	7
Sufficient illumination of the work area	4
Avoiding needs manpower for installation/operation of the machine	3
Sensors	5
Avoiding sharp edges	5
Safety equipment	7
Grounding equipment	1
Quick and easy adjustment	6
Easy maintenance	4
Release to production machines	1
Easy cleaning machines	2
Rapid rotation fixture	8
Acceleration clamping	5
Rigidity of	5
Correct mounting of the product	10
Correct position of the product	10
Use existing parts of existing machines	5

Rating scales functional requirements were divided into two groups.

0 ~ 5 => do not enter into QFD

6 ~ 10 => enter the QFD

The functional customer requirements are evaluated in the range of 1 to 10, where a value of:

- 1 represents the lowest, and
- 10 the highest importance value for the customer.

Evaluation of the functional needs of the individual is approved by the customer. The customer also agreed with my proposal evaluation scales which are:

- 1 ~ 5 => that will not participate to QFD.
- 6 and above will participat to QFD.

Customer at the conclusion of the meeting checked my evaluation of individual functional requirements and it has been approved.

3.3. House of quality diagrams

House of quality or “QFD”, is a tool to define the customer needs. The QFD is a simple diagram where we find technical characteristic on the top and customer needs on the bottom left side of the diagram. The idea is to make a match between technical specification and customer needs to see what values has to be improved and which one we should reduce to save the costs.

We use a simpl values which are:

- Value (1) means a lower relation between characteristic and needs.
- Value (3) means a medium relation between characteristic and needs.
- Value (9) means a higher relation between characteristic and needs.

By connecting characteristics and needs we come to technical specification of the innovated concept. For the tool concept, it will be spelited to two parts, upper part (screw-driver) and lower parts (product holder).

3.3.1.QFD for Screw-driver

Screw-driver is the main working tool to finalize assembling the product. The QFD is considered screw-driver type, the number and performance. Attention is focused on speed and the corresponding tightening torque screw-driver. One of the parameters is the number of the screw-driver and their corresponding operation sufficient power input. Dimensions workspace clearly limits the route where the driver can move. Therefore, in the diagram there is shown a strong correlation between the working space and the length of the feed screw driver in all three axes.

The QFD is clogged number of signaling elements and is expected to install light curtains. The number of such sensors and their size is again limited by the dimensions of the workspace.

Customer requirements are clearly defined. The most important are the speed of operation, safety equipment and lifetime of the equipment. Also for the customer, the accuracy and rigidity of the pointing device is important. The machine must be easily adjusted and must be light.

After the mutual correlations of machine parameters and customer requirements correlation weights of individual requirements were generated and the significance of the parameters were calculated. The last step was to set target values. In Tab. 5 (Annex 1) QFD diagram is shown for a screw-driver.

3.3.2.QFD for product holder

The product holder is a part of the machine on which they are mounted prefabricated parts. On this part of the machine there is the focus of reliability, simplicity, consistency and speed. It is important that the product is sufficiently and quickly flipped from one position to another, but it suffered its reliability.

All these parameters and requirements are listed in the chart for the product. An important requirement is the stiffness of the plate and noise when scrolling.

Increase the stiffness by increasing the plate thickness, however, this emphasizes the increase in the number of damping elements and thus the price. Increasing the thickness of the boards means growing its weight, so it is necessary to adjust the other two linear dimensions. All this is shown in the diagram.

On the board there are two positional clamping elements, which are designed to provide prefabricated parts in the desired position. For the function of these elements it is necessary to ensure an adequate supply of media. Customer again requires easy maintenance facilities, equipment life and availability of spare parts with ergonomics of the device. In Tab. 6 (Appendix 2) is shown QFD diagram for product holder.

3.4. Conclusion of QFD for screw-driver

On the basis of the calculated values of the characteristics of the final product was made in the evaluation of proposed values statement. Target values define the final parameters of screw-driver. The significance is higher, the higher of the value of the target parameter than the proposed value.

Examples of significance of parameters: load servo, speed screw-driver, length axis servo feed rate screw-driver, the torque screw-driver torque required tolerance, tolerance position servo system to the point of use. With these characteristics, the significance increases and at the same time we have to get better parameters. Detailed information is given in Annex QFD Diagram for screw-driver.

3.5. Conclusion of QFD for product holder

The same way was prepared for QFD fixture machine or product holder. Again, the same way of logic evaluation based on the significance of individual characteristics of the product. QFD diagram is shown in Annex.

Due to the fact the QFD diagrams has a lot of information to talk about, I won't talk about all details because this might make the work thesis longer and longer. Much information could be found in the QFDs in the annex, such as: comparison between innovated tool and the exisiting tool and also other informations. Details presentation about the QFD will be done during work thesis presentation in front of the commission.

3.6. Technical specification

We define technical specification of machines on basic characteristics of the devices, which are essential for the final design of the equipment and have a well-defined target value.

In Tab. 5 there are the technical parameters that require the newly designed equipment. When designing equipment and component, the selection must take into account such endpoints.

It is also necessary to bear in mind the standard parameters and standards that are set by the law and regulations of the country in which the equipment will be used. For example, it may be the power supply of the machine, which is in our case a standard voltage 240V socket.

Technical characteristics of the devices also affect local regulations, such as requirements on labor safety, fire regulations and internal rules of the company.

Tab. 5 Technical specifications [5]

Screw-driver		Product holder	
Characteristics	**Value**	**Characteristics**	**Value**
Height inside workspace	1300 mm	Number of screw drives	1 pc
Width inside workingspace	1300 mm	Angle of rotation fixture	90°
Depth inside workspace	800 mm	Speed clamping	0,5 m/s
Length X axis servo system	600 mm	Speed rotation preparations	0,5 m/s
Length Y axis servo system	550 mm	Height inside workspace	700 mm
Length Z-axis servo system	500 mm	Width inside workingspace	650 mm
Feed rate screwdriver	2,5 m/s	Depth inside workspace	380 mm
Capacity of servo system	30 kg	Load of table	max 10 kg
Speed of screwdriver	500 ot/min	Height of the work plane of component	1000 mm
Tightening torque of screwdriver	1,2 Nm	Length of the laser protection barrier	1000 mm
Tolerance desired for torque	± 0,1 Nm	Working pressure pneumatic clamping system	0,5 MPa
Tolerance position servo system to the point of use	± 0,1 mm	Working force needed by manpower	Max 50 N
Axis angle to the axis of the hole screwdriver product	0°	Number of fasteners	2 pcs
Height screwdriver to the product	500 mm	Number of signaling elements clamping	2 pcs
Working force needed by manpower	10 N		
Number of security features	3 ks		
Length of the laser protection barrier	800 mm		
Noise screw device	< 80 dB		

3.7. Morfological matrix

The morphological matrix is a method of creative solutions to critical problems. It represents a matrix analysis of all functions and possibilities of technical solutions to the market functions. In principle, consists of a description of all the functions and components of investigational describe all variants existing in the market. It is also possible to combine different options that may work, in order to get an overview of the design and technical solutions to one problem.

For a combination of possible solutions I have used morphological matrix (Tab. 6). The aim is to create a matrix be innovated concepts of technical solutions, which subsequently developed into policy options. Furthermore, these conceptual solutions will evaluate each solution and then they based on key evaluation parameters and their total weight selects the optimal solution to the final solution design new machines.

In the left column of (Tab. 6) there is a list of all the features of the current solution, in the right hand column there is a list of all existing technical solutions on the market. Further details are given below.

Tab. 6 Morphological matrix [6]

Part	Function	Characteristics			
Screw driver	Drive of screw driver	Fixed	1. Axe	2. Axes	3. Axes
	Movement	Fixed	Manual	Manual with server	Robot
	Screwing unit	1 Unit	2 Unit	3 Unit	6 Unit 2x
	Orientation	Right	Left	Both	
Product holder	Movement	Fixed		Moving	
	Type	Fixed	1 Axe	2 Axe	3 Axe
	Orientation	Fixed	Right	Left	Both

An analysis of the morphological matrix can generate several possible technical solutions. The task of this thesis was to design at least three conceptual solutions and systematically decide on the selection of the final solution.

From the morphological matrix, I chose five technical variant solutions that are combined various technical solutions. Selected solutions I developed in the next chapter.

According to the morphological matrix, we are able to find more than five solutions, but for better understanding with regard to the requirement of the diploma thesis, I chose only five solutions, which are discussed further in Chapter 4.

4. Technical concept solutions

Fro the morphological matrix (Table. 6), we can figure out at least five variant technical solutions. Those solutions will be implemented and explained in detail in this chapiter.

4.1. Variant solutions

By taking a look to the combination of need of screw-drivers and product holders, I came up with the following technical proposals. Those are combinations of already existing technical solution on the market by combined in different ways which make them innovative.

Those solutions I propose are only to fit with the requirement of diploma thesis which is limited to minimum 3. To make the innovation propousal more competitive I will propose 5 technical solutions. More information could be found in the chapter below.

4.1.1. Option A: Automatic screw robot

One option is to use the assembly fully automated cells. On the workspace cell there is placed a robot, which has six degrees of freedom. The robot is mounted electric or pneumatic screw-driver of the appropriate shape of the pin. On the working table, there is placed product. The cell is fully automatic with all the safety features and can be included in the production line.

Automatic screw robot saves the time required for an operation that will have a significant contribution to production. If the product is fixed on the table, it is necessary to perform 3D tool movement with six degrees of freedom. This is a technical solution that will greatly facilitate the work of the operator, but also assumes substantial financial investment. A simple schema of application is shown in Fig. 20.

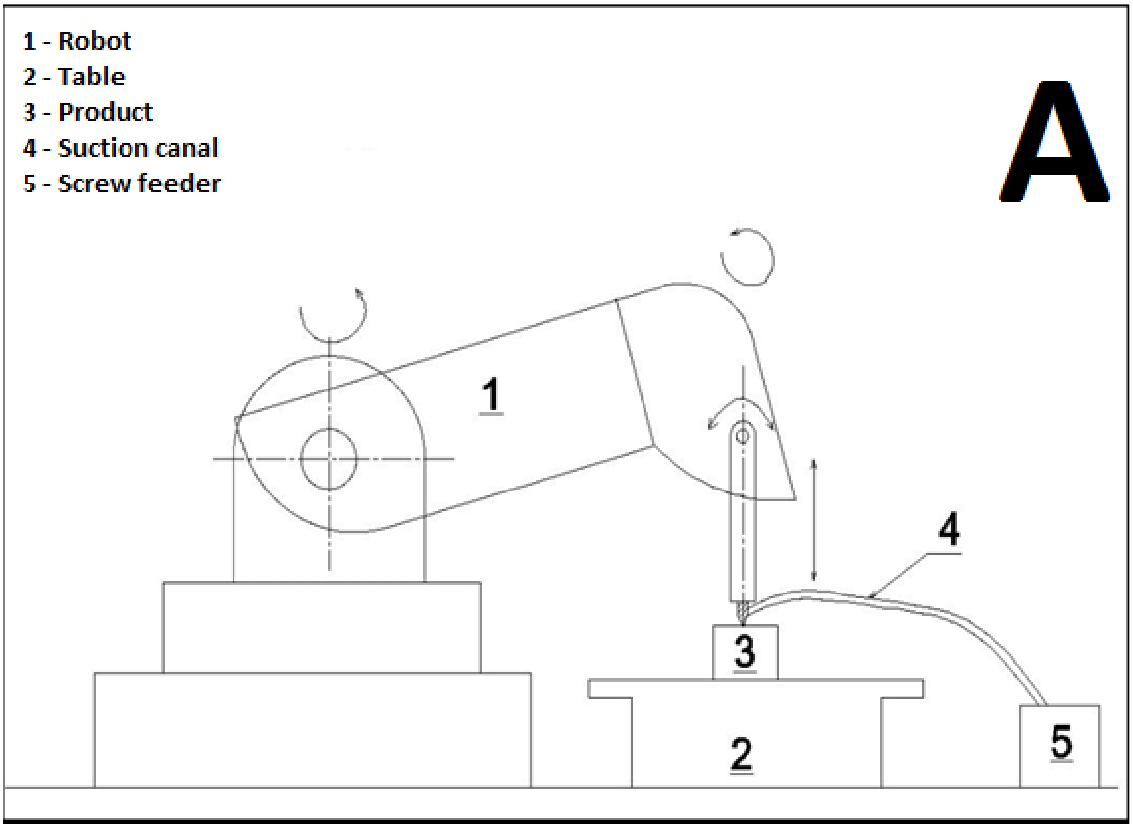


Fig. 20 Schema robot with a screw-driver moving and fixed product [20]

4.1.2. Option B: Robot with a screw-driver fixed and floating product

There is also introduced a similar principle as in the previous design with two differences. First robot holds a desk on which are precisely defined a position established assembly parts. The table moves in all axes and angles and thus has 6 degrees of freedom. On a related frame are newly placed two screw-drivers (it could be pneumatic or electric). These screw-drivers are held fixed and only the rotational movement of the pin. By increasing the number of screw-drivers is reduced working time, but this goes in parallel with increases the cost of establishment.

This solution seems to be very complicated due to increased demands from the construction and by the final implementation. The price will be significantly higher than in the previous design. The time required for implementation will be much longer and can be expected more technical problems even in the case of assembly and adjustment. Moving around the table can be expected to be much slower than the movement itself of screw-drivers, which brings bad effect in terms of savings Lead-Time. Still, there are available technical solutions that can be further developed in the future. A simple application scheme is shown in (Fig. 21).

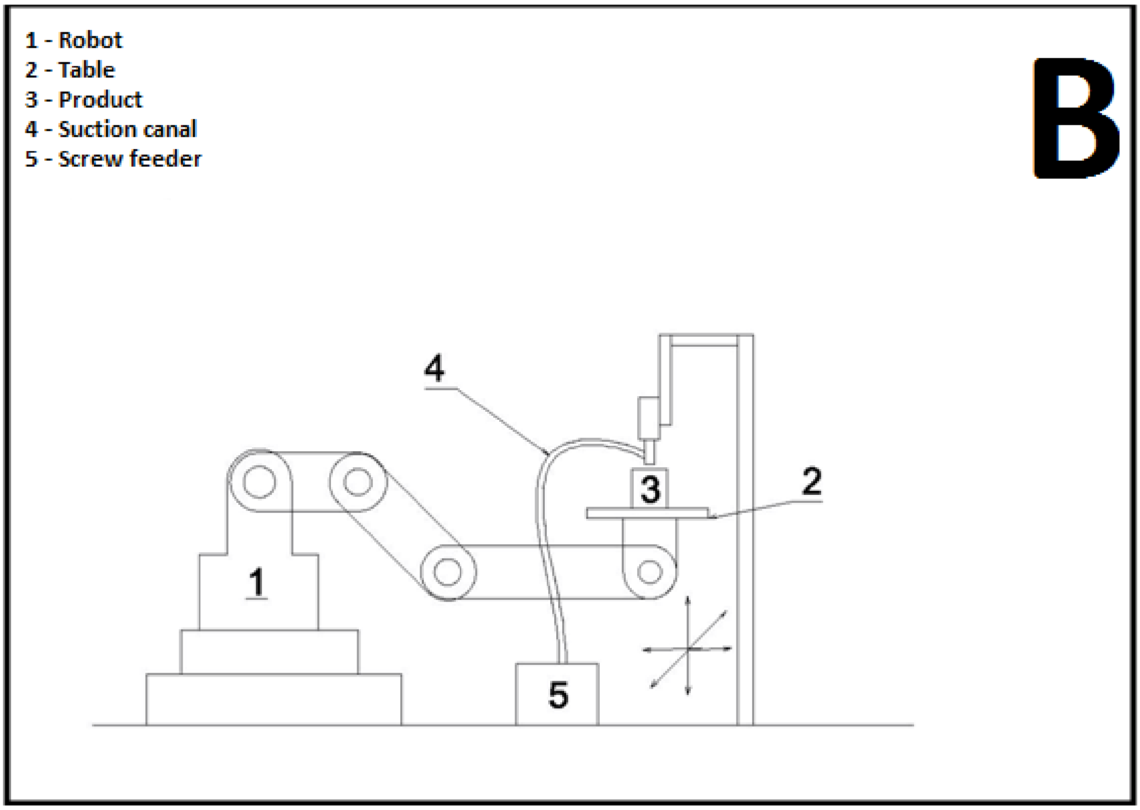


Fig. 21 Scheme of the robot with a screw-driver fixed and moving product [21]

4.1.3. Option C: Servo unit

At present, the widespread use of servo elements during assembly processes. In the proposed solution there are used of linear motion displacements using ball screw or toothed belts. The draft work table is based on three linear displacements, which allows movement in the horizontal plane. To reduce the required working time two screw-drivers are used and prefabricated components are set up symmetrically.

Both screw-drivers are trapped on the third linear displacement and held vertical reciprocating movement along the vertical axis. Each linear displacement is fitted with an electric motor and sensor.

Depending on the position of deduction feed sensor ensures high repeatability of the table and low hysteresis. Simple application of the scheme is shown in (Fig. 22).

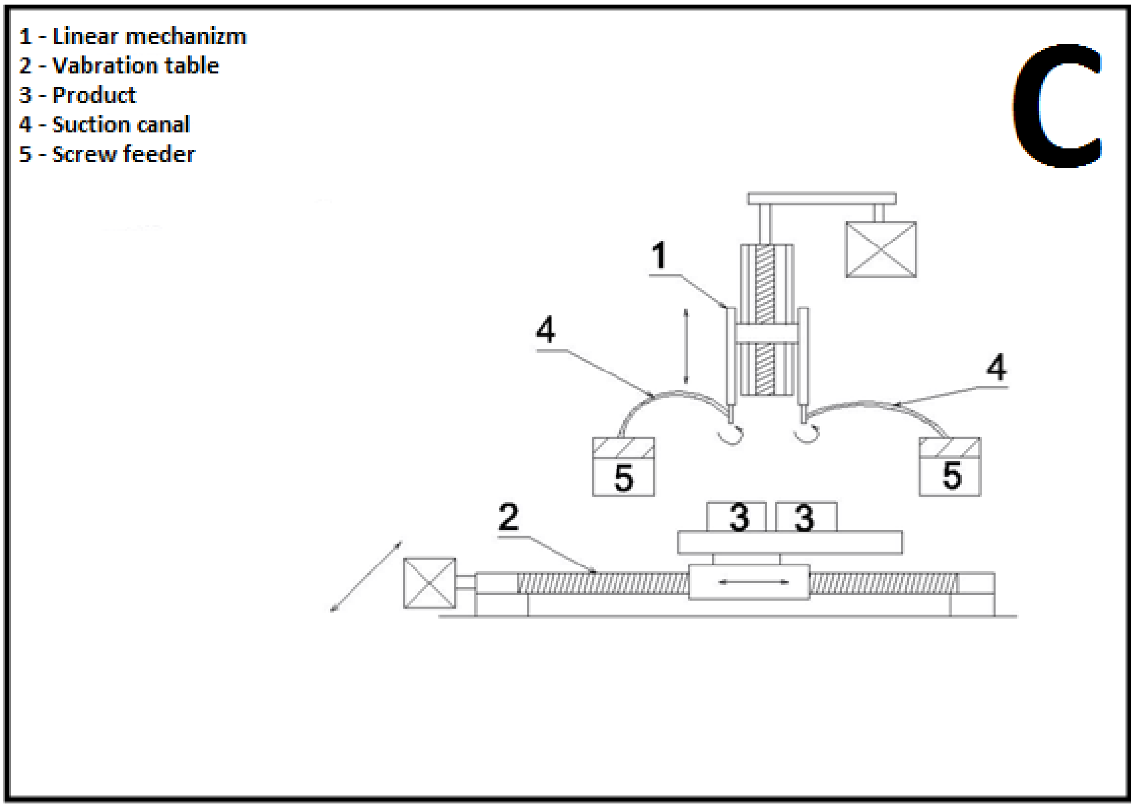


Fig. 22 Scheme of Servo drives [22]

4.1.4. Option D: Camshaft

Option D assumes the use of fixed screw-drivers in combination with the movable table, wherein the screw-driver is held only reciprocates vertically. Movement of the table will be performed by a cam. This solution is also feasible, but it is necessary to think in advance about a challenging technical proposal rotation table in a horizontal or vertical axis. In principle it is possible to derive at least three technical solutions, but given the similarity principle, these options considered and compared with other proposals as a whole. Variants of this case are:

- Fixed screw-driver with movable table in the axes of the Cartesian coordinate system as a rotation around the vertical axis.
- Rigid screw-driver with the movable table in the Cartesian coordinate system axes and rotation about a horizontal axis, but with modified product holder.
- Attached to the product table with the movement of the axes of the Cartesian coordinate system and two screw-drivers moving in horizontal and vertical plane.

Table movement may be performed by the cam profile and not have to drive in three separate axes drives. Listed below are the cases of using a cam movement. The disadvantage of these solutions is time-consuming production cams and commissioning process and total need final testing trajectory.

Moreover, this solution in terms of elasticity changes inflexible product variants. Another major disadvantage is the difficult possibility of any modification trajectory. Simple application of the scheme is shown in (Fig. 23).

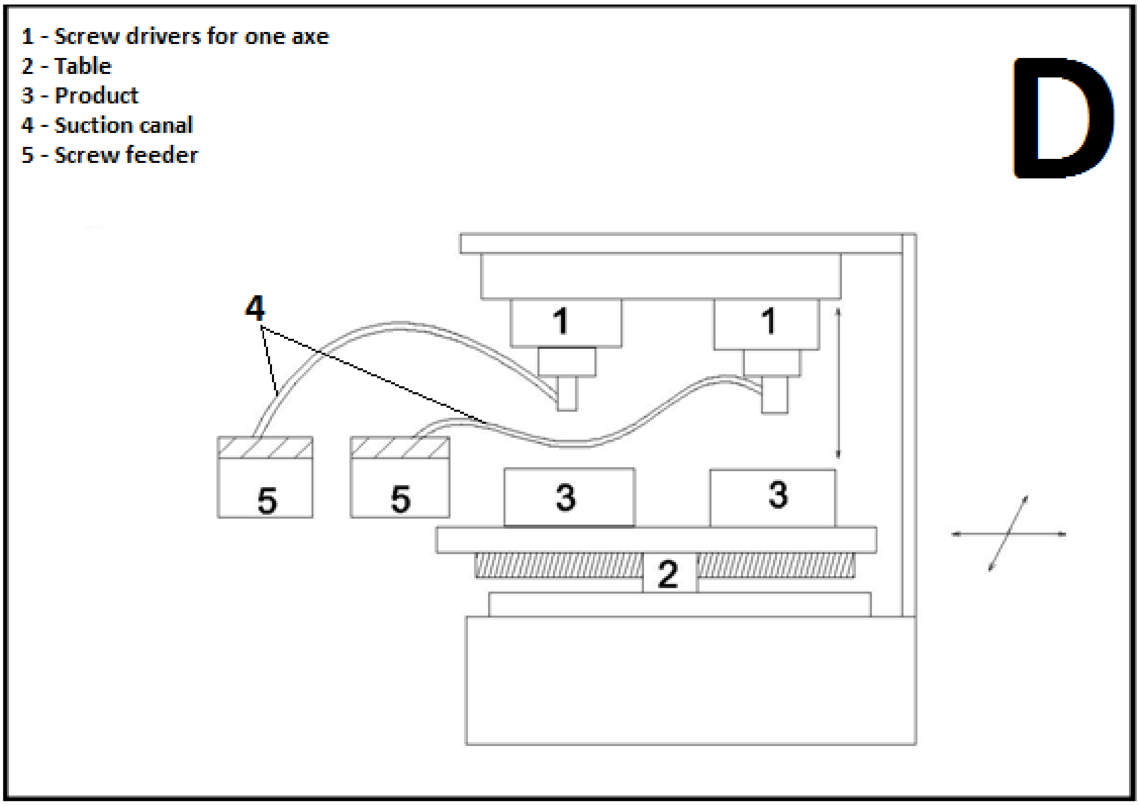


Fig. 23 Scheme of Camshaft [23]

4.1.5.Option E: Screw-driver and rotary pneumatic cylinder

Another proposed solution uses only pneumatic components. The frame is mounted pneumatic control system for linear displacements, which take place in the movement of all axes of the Cartesian coordinate system. At the end of the displacement along the vertical axis is positioned pneumatic screw-driver. On the desk are created shaped stopper. These stoppers are caught bottom of assembled parts by pneumatic cylinders. This is a centered position of the component on the table and at the same time there is a fixation. The working table is attached to the frame by means of two pneumatic rotary actuators, which ensures rotation of the table 180 upon completion of assembling the parts.

Then loosen the two pneumatic cylinders and assembled components fall into a container.

The essence of the proposal is a screw-driver fixedly connected with a servo mechanism that can move the XYZ together with the pneumatic cylinder, which is associated with the product, and is capable of rotation. Simple scheme is shown in (Fig. 24).

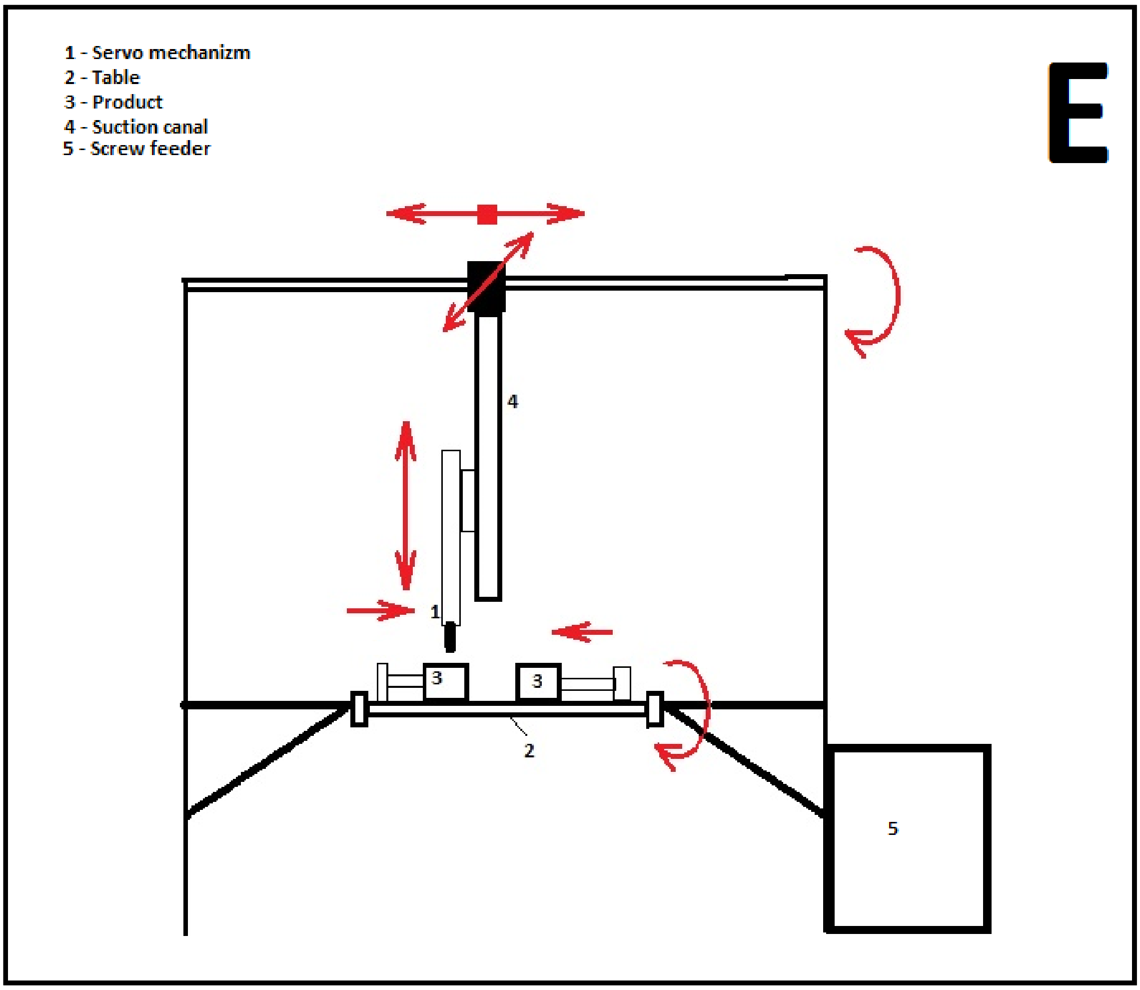


Fig. 24 Scheme of a screw-driver rotary pneumatic cylinder [24]

If necessary, a further increase in the capacity of work and thus the productivity of the machine, in all variants can be accelerated by adding further cycle screw screw-driver. This option is not required to, so let's take this solution as the potential of the future. The following paragraph is only possible explanation of the functionality of the x-fold screw head.

4.2. Possibility to use more head screw-driver at once

Already mentioned option is to design solutions to reduce working time. To minimize the working time, we can use multiple screw-drivers on each head, which greatly increases costs, but also ensures savings in working time. Therefore, it is intended to replace each screw-driver by the trio screw-drivers. Such module comprises a drive shaft, whose end is fixed to a larger sprocket. At this turn about three smaller gears that transmit torque to the three driven shafts. The ends of the shafts are fitted with screw pins. The spacing shafts are identical spaced bolts on parts assembled. To drive both drive shafts used one motor, the torque is transmitted via the belt drive. Both modules come together along the vertical trajectory of the mounted components and the engine spins all six together and driven shafts will screw bolts. Simplified scheme is shown in (Fig. 25).

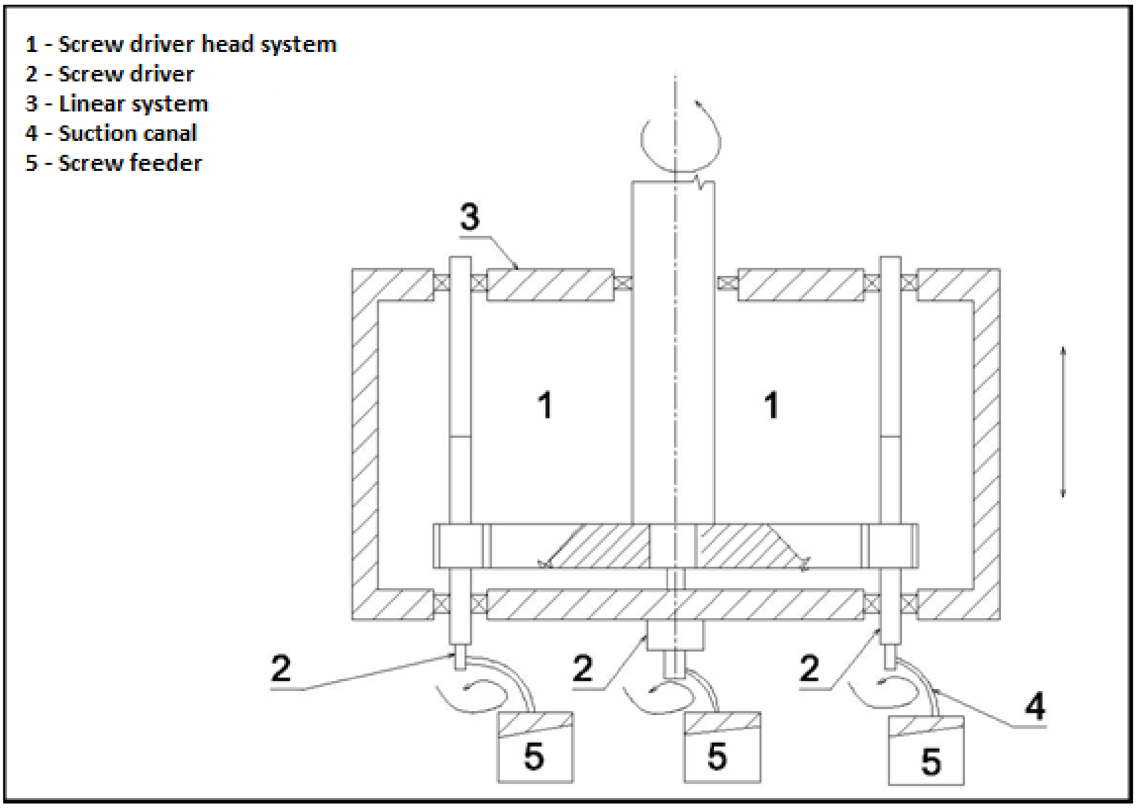


Fig. 25 Scheme of a three-axis head screw [25]

Driving the axes of screw-drivers can solve a variety of connection methods, such as using a belt, chain, etc…This solution will not be included in the selection of an optimal solution because it is an option, which can be applied to all variants.

4.3. Optimal solution selection

To select the most suitable design there are a number of methods which can be derived to a final solution. In introduction to exclude the so-called "Weak solutions" we will use a simple method. Rough classification concepts and detailed in the subsequent selection is compared to the remaining concepts. Below there are the variants and their names (Tab. 7). All proceed to the evaluation of the selection of an optimal solution.

To evaluate and select the most appropriate solution in this case, proceed directly to a detailed comparison of all solutions. The intent is to compare all six independent solutions proposed among themselves with regard to the defined initial criteria. For the final comparison will best serve decision matrix that takes into account the different criteria and defined their weight. For ease of clarity, I decided to use a simple system of a pair of characters. The system with symbols is below:

- Symbol (1) means that the option fulfill the functions
- Symbols (0) indicate that the variant does not meet the function

More information could be found in the (Tab. 7).

The winning design, by this method will be the one for the decision-making proposal which is in our case variant E. This solution is among structurally and operationally simpler solution. Further, the above excellent properties of propousal are in respect of technological requirements and quality aspects. From the viewpoint of purchased components, this solution lies in the minimum load zone. In other of evaluation criteria is evaluated positively solution to neutral. Based on this assessment, I decided to further focus on development of variant E, which seems most appropriate to achieve the objectives set at the beginning of thesis

Tab. 7 Comparison of variants [7]

Parametr	Variant A	Variant B	Variant C	Variant D	Variant E	Weight (%)
Price	0	0	1	0	1	53
Parametr *Weight	0	0	53	0	53	
Easy maintenance	0	0	0	0	1	3
Parametr *Weight	0	0	0	0	3	
Change from Auto to Manual	0	0	0	0	0	2
Parametr *Weight	0	0	0	0	0	
Tack - time	1	0	0	0	1	12
Parametr *Weight	12	0	0	0	12	
Environment	1	1	1	1	1	1
Parametr *Weight	1	1	1	1	1	
Tool weight	0	0	1	0	1	2
Parametr *Weight	0	0	2	0	2	
Complexity	0	0	0	0	0	3
Parametr *Weight	0	0	0	0	0	
Tool lifetime	1	1	1	1	1	9
Parametr *Weight	9	9	9	9	9	
Energy need	0	0	1	1	1	1
Parametr *Weight	0	0	1	1	1	
Safety	0	0	1	1	1	1
Parametr *Weight	0	0	1	1	1	
Maintenance costs	0	0	0	0	1	1
Parametr *Weight	0	0	0	0	1	
Simplicity	1	0	1	0	1	3
Parametr *Weight	3	0	3	0	3	
Shorter production time	0	0	1	0	1	7
Parametr *Weight	0	0	7	0	7	
Easy construction	0	0	0	0	1	1
Parametr *Weight	0	0	0	0	1	
Noisicity	1	1	1	1	1	1
Parametr *Weight	1	1	1	1	1	
Total number of points	**5**	**3**	**9**	**5**	**13**	**100**
Successfulnest in %	**33**	**20**	**60**	**33**	**87**	

4.4. Final concept

In the final draft it will be based on already existing design tools, which I will have to modify so as to achieve the desired result of the selected winning solutions. The final design concept will be a variant E.

The newly proposed machine will consist of the following elements:

- Frist, the existing frame of the machine will be used, this frame is already used in production.
- Second, clamping table (product) will use existing, existing and fully meets our requirements. To automate the positioning of the existing product supplemented by part-turn actuator. This will serve to drive the rotation of 90 ° (to set the product to the job when joining).
- Third, rotary drive is part of a standardized catalog from Festo. Part is chosen from the catalog on the basis of the required parameters. Approximate cost of

equipment employed 10 000 CZK. Delivery time is 2 weeks from ordering.

- 4th, Pneumatic screw-driver with screw feeder is also supplied complete equipment from specialized firms engaged in automated screw-driving and screw construction vibratory feeders. Manufacturers of these devices can be firms Weber, Deprag etc. Price device is around 100 000 CZK. Time of production of the equipment according to customer specification is 12 weeks. This time can be reduced in case of needs.
- 5th, Side screw-driver, I will use already existing. The screw-driver will be supplemented by a linear actuator to its positioning. The price of the drive is included in the price of the upper positioning system.
- 6th, Servo mechanism for positioning the upper screw-driver is supplied by Festo as a complex system including positioning axis for the driver side. This product is a "know - how" Festo. Price of the complete device is 400 000 CZK. Time delivery device for three months.
- 7th, Lighting for ensured through standardized industrial luminaires. The price of the average Fixtures enabled 2 000 to 4 000 CZK.
- 8th, sensors are used in standard catalog components of renowned manufacturers. Price employed up to 10 000 CZK. Sensors ensure the safety of the machine due to the manual and if necessary, stop the machine operator's presence in the machine.
- 9th, the control panel on standard panel is used to control the servo mechanisms and the quotation of the company FESTO. The control panel will be included to the cost of servo mechanisms.

5. Construction design

The goal of Chapter is to describe future status of station after construction and also to compare its current and final state.

Furthermore chapter answer the question *"what solution can we propose to assemble the product without screwing?"*. Options bonding without screwing operations that would have been theoretically possible provided if the customer has agreed with this variant. At the end of the chapter is application of egergonomic tools to improve the current status.

5.1. Assembly of product without screwing

Screwing is operations required by the customer, the purpose of which is the combination of air canal with stepper motors. The question in the process of innovation is that it is not possible to achieve fusion product without screwing operation, or screwing limit. From a technical point of view it is possible to use auxiliary products.

5.1.1. Cylinder head screws

One way of reducing the screwing time is screw shaft is divided into two parts. The first half of the screw is smooth and the diameter of shank is smaller than the smallest diameter of the thread, which is equipped with the second half of the screw. During operation the first half of the screw inserted into the connected parts and after screwing components that are attracted to each other. Such a screw is shown at (Fig. 26).

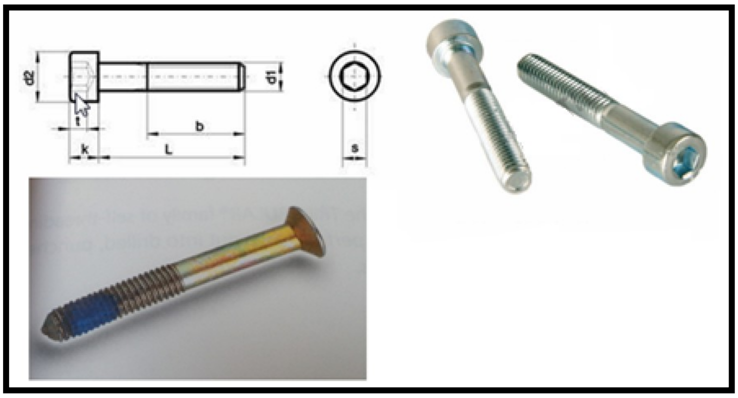


Fig. 26 Example screws with split shaft [26]

5.1.2. Trilobular screw

Reduction of time screwing can be achieved also by using trilobular screws (Fig. 27). They have the ability to carve thread during their insertion into pre-drilled holes. The advantage of the screws is minimal contact area and thus minimizing the resistance of the material. Maybe a limiting factor is in this case higher price.

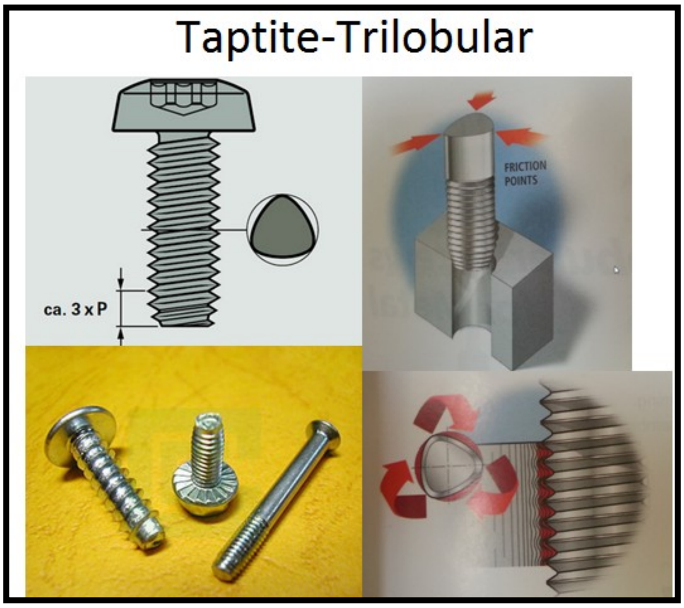


Fig. 27 Example of trilobular screws [27]

5.1.3. Tik-tak system

Known technical solutions that can be applied to the current state are known under "Tik-tak" system witch we can see in (Fig. 28).

It consists of two rotating parts. One serves as a guide and at the end of the slots. The second rotating element is a shaft which is mounted on one end of paws.

After inserting the shaft into the end position and after turning the lever to fit the slots and drive to the merger of the two components. The shaft abuts the spring which serves for inducing the preload for the rigid connection, while when removing ensure spontaneously eject shaft of the guide component. The disadvantage is the inability to purchase as part of a standardized and therefore need to ensure externalproduction.

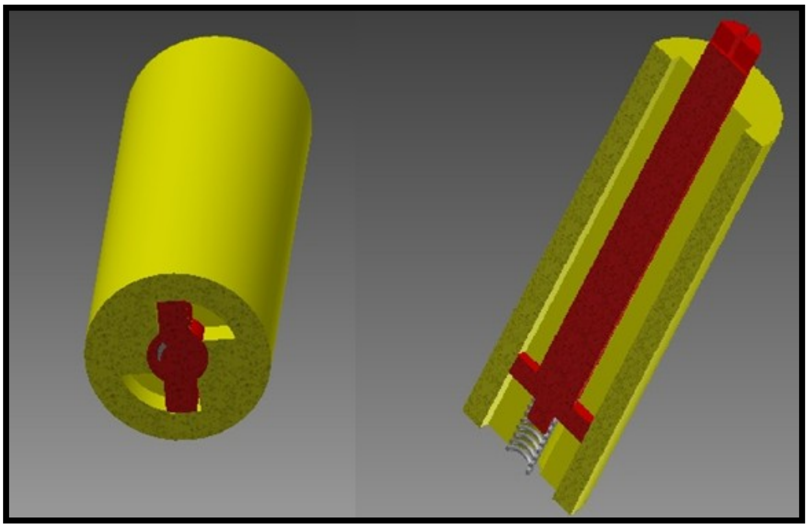


Fig. 28 Tik-tak system [28]

5.1.4.Design calculation

Torque moment

$$F = 2N$$
$$D = 10mm(0,01m)$$
$$M = F.\frac{D}{2} = 2.\frac{0,01}{2} = 0,01Nm$$
$$M_k = M.\cos 0 = 0,025.1 = 0,01Nm$$

Wire diameter

$$M_{k8} = F_8.\frac{D}{2} = 15.\frac{0,01}{2} = 0,01Nm$$
$$d_i \geq \sqrt[3]{\frac{16.M_{k8}}{\pi.\tau_{DK}}} = \sqrt[3]{\frac{16.0,01}{\pi.50.10^6}}$$
$$i = \frac{D}{d_i} = \frac{0,01}{0,001} = 10$$
$$K = \frac{i+0,2}{i-1} = \frac{10+0,2}{10-1} = 1,13$$
$$d_{i+1} \geq \sqrt[3]{\frac{16.M_{k8}.K}{\pi.\tau_{DK}}} = \sqrt[3]{\frac{16.0,01.1,13}{\pi.50.10^6}} \qquad = 1mm$$

From the catalog I choose the wire diameter d = 1 mm pitch and spring diameter D = 10 mm.

Spring length

$$k = \frac{\square}{\square} = \frac{\quad}{\quad} = 200\frac{N}{m}$$

$$n = \frac{G.d^4}{8.D^3.k} = \frac{0,8.10^5.10^6.0,001^4}{8.0,01^3.200} = 5$$

$$l_0 = \square \qquad .n + d.n + d.n_z = 10 + 0,5 + 5 + 2 = 17,5mm$$

5.2. Cooperation of product holder and screw driver

The product holder is a very important part of construction, with the screw-driver they are the main one. It's a very important to make sure that the movement of both components is in parallel and fits exactly 100%. Any delay of one of the parts can make a product defect and create a trouble with customer. So it's very important to achaine the both works on the same landline to avoid none needed issues.

Synchronization of the movement of table with servo mechanism of the screw driver will be instated and managed by company FESTO, because both needed components (Servo mechanism and rotation actuator are purchased from FESTO). I already consulted this with company FESTO and they guarantee and ensure the cooperation of both components to fit with each others.

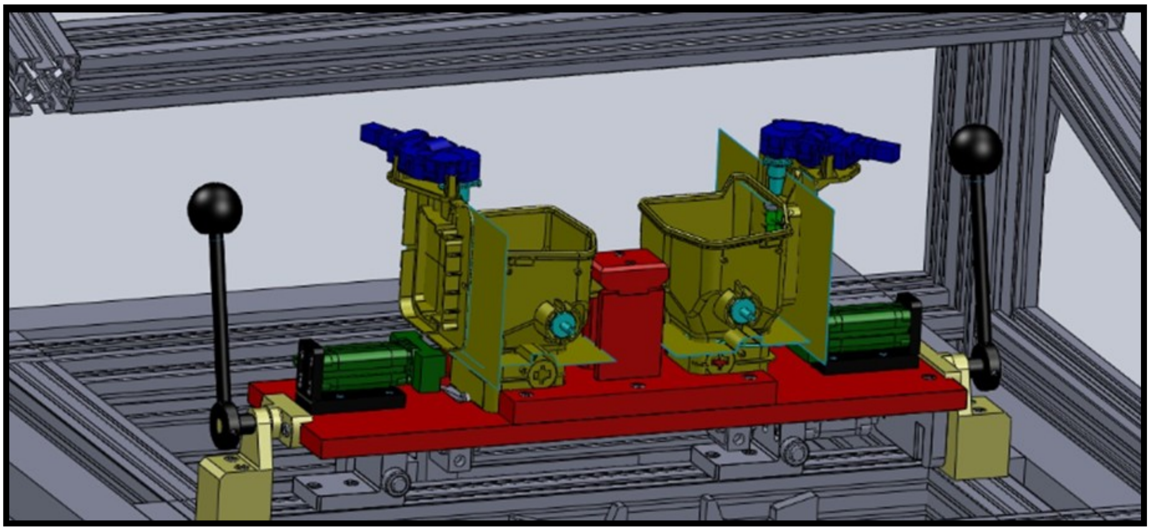


Fig. 29 Product holder [29]

5.3. Future status of tool after modification

The new state machine will consist of a number of added positions (Fig. 30 or Annex 4).

The machine consists of:

- Existing main frame with a work desk with product.
- Pneumatic screw-driver.
- Servo mechanism.
- Pressure screw-driver.
- Rotary actuator.
- Control panel.
- Side screw-driver.
- Resources for eletric control.
- Packaging (Multipack).
- Lighting.
- Optical sensors.
- Vibrating screw feeder.
- Table to hold vibrator screw feeder.

All of those components will be assembled to the new work station and it will be needed to make sure that all of this will work together.

Before making a good receiption of the tool, there is an internal process of company BEHR to confirm the reception of the tool. This tool must be released by internal quality of BEHR. To have such release it's important to submit the PPAP documents.

Those documents are a must to have for the quality and as we are using many suppliers for this project, we will request from them to provide us with those documents as well.

PPAP documents are always costing, that's why I requested from suppliers to include PPAP costs to the offer. This means that in the chapter 4.4. Final concept, the prices are mentioned with including the PPAP costs as requested by quality.

Why the PPAP is important is that PPAP confirm that everything works together and very well, with only such confirmation we can pay the suppliers. Without it the finace department of BEHR can't release any payment to suppliers.

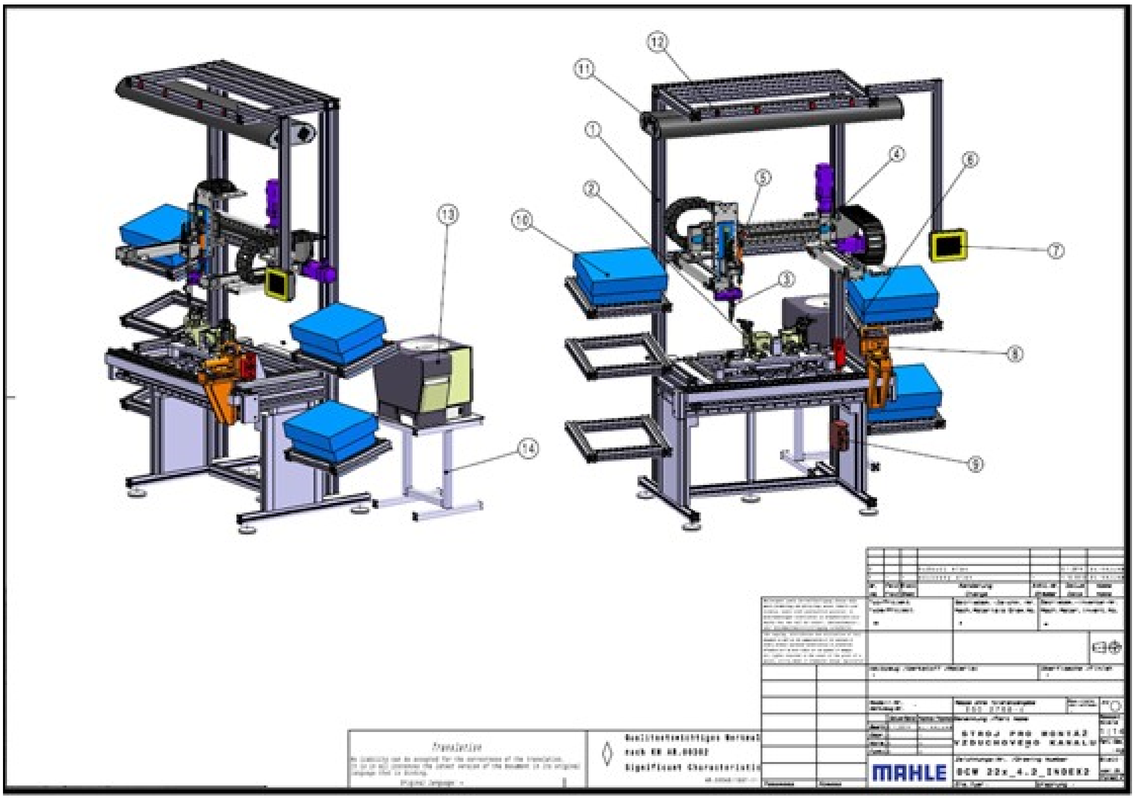


Fig. 30 Final state of the machine after repair [30]

5.4. Analysis of proposed components by method FEM

After the construction it's necessary to analyze the designed parts using the finite element method. The aim of this analytical method is to analyze possible future distortion of the parts and in the case when the deformation value is greater than 3 MPa, to take measures that minimize risk. The first analyzed the work of the rotary table (Fig. 31 is also given in Annex. 5), it is put on the product (double product, left and right).

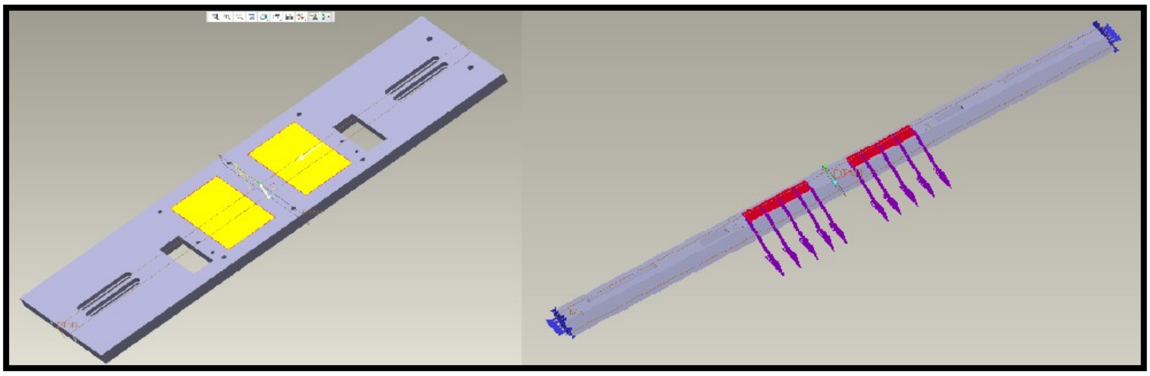


Fig. 31 Application of FEM on desk [31]

The yellow pad (Fig. 31) was applied corresponding to a pressure of five kilograms. I analyzed the effect on the surface of the resulting deformation (Fig. 32).

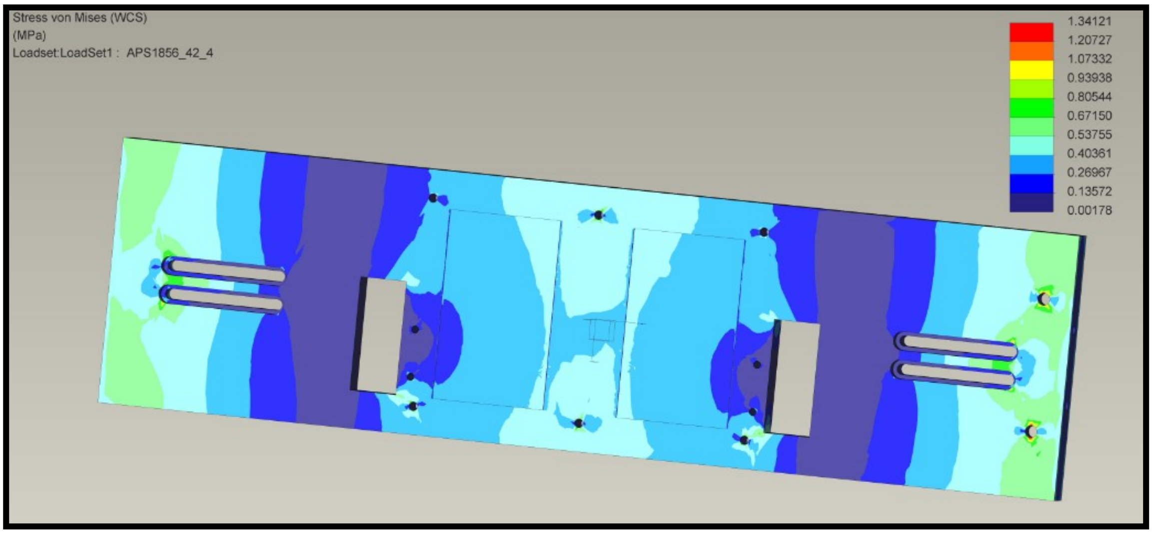


Fig. 32 Desk deformation [32]

As shown in the illustration (Fig. 32) resulting deformation is small and has no effect on the plate. However, it is necessary to allow for the fact that the plate has a life cycle of ten million cycles, and the change is necessary before reaching the highest durability.

To improve the structural analysis I marked beside yellow areas (Fig. 31) further applied load and the total volume of the desk. To the projected structural design load, I doubled the weight on the plate (instead of 5 kg, a load of 10 kg was tested). Visualization of the resulting deformation is obvious from (Fig. 33). On the basis of structural analysis, it can be stated that the proposed materials and construction are sufficient.

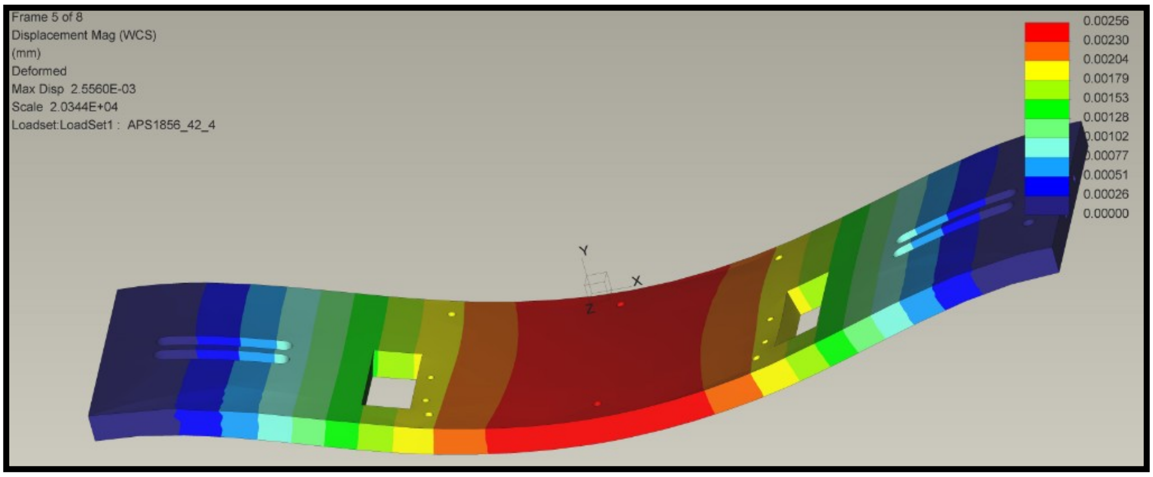


Fig. 33 Deformation of the total area of the plate [33]

In the case of a test strain of the rotary shaft, it has been performed in the same way as in the case of a test desk surface. First a modeled shaft design was created, for which construction was chosen a suitable material. To assess the possible deformation, it has been applied pressure corresponding to the load of 15 kg, which corresponds to three times the expected load to desk. The aim of the analysis was to verify that the rotary shaft will be fully functional, that is able to rotate the plate without complications. The result of the analysis using the finite element method is demonstrated in (Fig. 34). The drawing is presented in Appendix. 6.

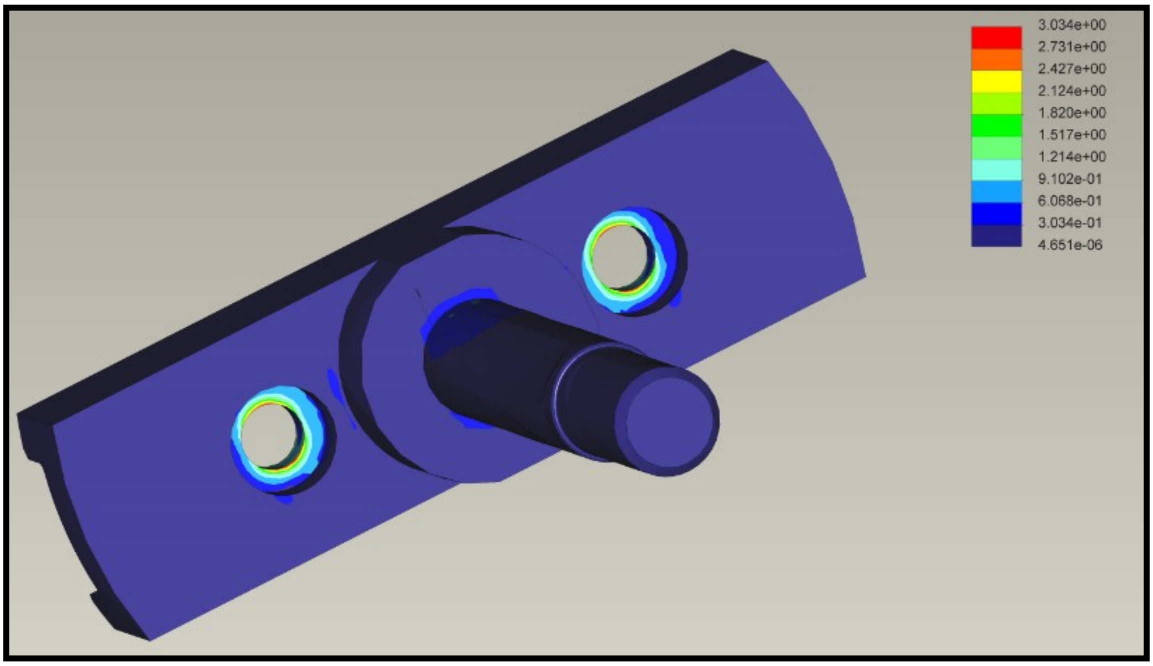


Fig. 34 Deformation of the rotating shaft [34]

The result of the analysis showed that the deformation is weak and only in areas conjunction with the rotating shaft plate with screws. Based on this finding, it is advisable to use standardized pads for strengthening the link.

The results of the analysis by FEM show only small deformations. To get more accurate and detailed results therefore recommended that the fatigue test. It is not required to test the rotation shaft.

The third proposed work is the holder shaft. Its task is to hold the rotating shaft so as to carry out the transfer of torque from the rotary drive to the motherboard. This part I analyzed using FEM. The reason is the simplicity of the part and on the other side of its high friction force sufficient for the rotating shaft.

Part will be produced externally with suppliers and allowed to easy assemble on the rotary table. The turning number (Fig. 35) also can be founed in annex no. 7. Below is shown how the part should look like at the 3D model.

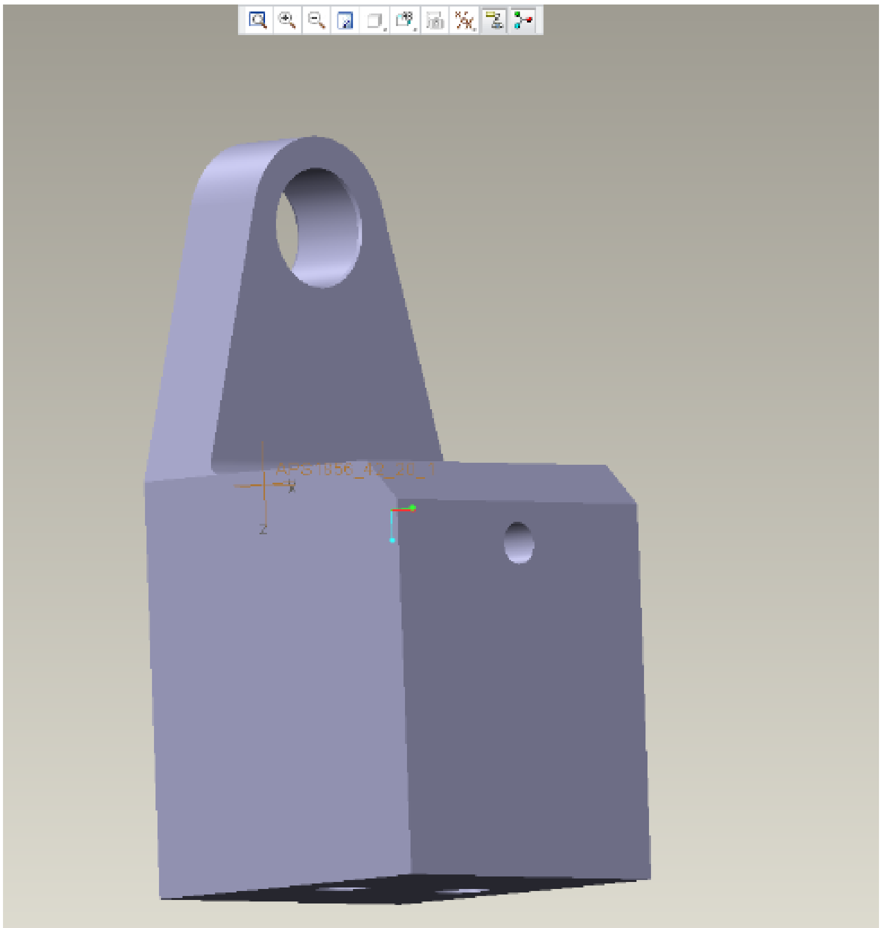


Fig. 35 Holder shaft [35]

Drawings of parts and future status of the machine will be part of the Annex.

5.5. Comparison of current and planned machines status

For better understanding and comparison of conditions of the machine before and after the design, a list of comparision has been listed in (Tab. 8). The new design brings several changes not only in the component, but also in the way of operations control. The purpose of verification is to ensure a higher quality of operations and thus also the assurance that the product has no defect or problem that visual inspection may not reveal.

Tab. 8 Comparison of the current and innovated machine status [8]

	Part	Actual status	Future status
Tool	Basic tool	Same status	Same status
	Light	Don't exist	Will be implemented
	Senzors	Don't exist	Will be implemented
	Control panel	Don't exist	Will be implemented
	Possibility to stop tool	Don't exist	Will be implemented
Screw driver	Control of screwing system	Only by operator hand	Automatic - by servo mechanizm
	Upper screw-driver	Pneumatic by hand control	Pneumatic - by automatic control
	Lower screw-driver	Pneumatic by hand control	Pneumatic - by automatic control
	Control lower screw-driver	Manually by operator	Automatically using linear guides
Table	Way of holding in table	Manually by operator	Automatic use of a pneumatic cylinder sensors
	Rotation of table	Manually by the operator (manual lever)	Using automatic swinging drive
Control	Fit of axes between screw-driver and hols for screwing	Manual (Hand)	Automatic servo mechanism using a reciprocating drive
	Control of full rotation of screw	Visual	Automatic approval machine

5.6. Ergonomics of equipment

Ergonomic rules are defined by laws and regulations, national governments and are required to follow them. Therefore, it is important to think about these properties already in process equipment design and incorporate them into the design of the equipment at this stage. Particulares not needed has been eliminated to avoid any additional costs, to adapt the workplace with the equipment in the process. Actually, the device allows symbiosis of the machine done by operator in (Fig. 36). Also shows the ergonomic implications of upper limb.

In (Fig. 36), is shown the area which can be handled by operator with or without fatigue. The area is divided to 3 zones, which are explained below:

- Area A - for frequent and precise movements, the area for grasping small objects. Very confortable for operator to work in.

- Area B - the movement of the fore arm and manipulate objects without changing the basic working position. Less confrotable in comparision with Area A.
- Area C - the maximum ranges for distance less frequent and slower movements with the possible need to rotate the lever. This area is not favorable for operator to work in, that why the recomondation will be to avoid having any work steps there.

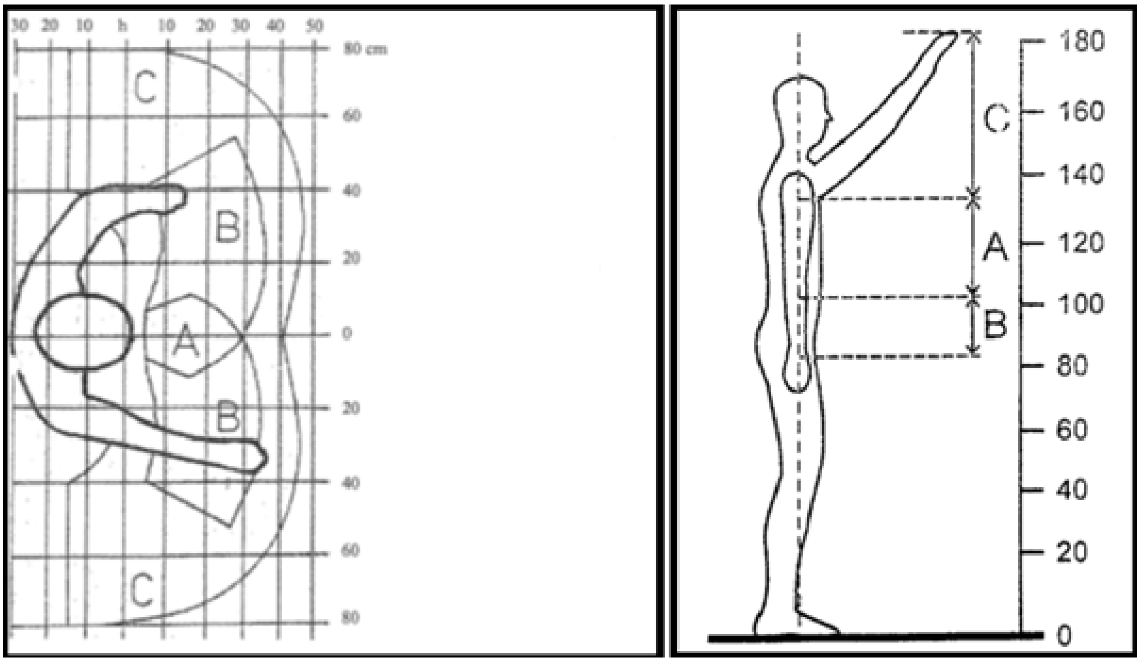


Fig. 36 Ergonomic ranges to reach by operator [36]

Height of working plane must match the physical characteristics of the employee base working position, the weight of objects, etc.., which is used in the operation, and visual demands.

The optimum height of the working plane is at work standing between:

- Men are between: 1020-1180 mm.
- Women are between: 930-1080 mm.

The best solution to create a good workplace is creating a fully adjustable workplace from beginning of construction. One solution can be used is electric drive which is fully useful working position for both small and large operators. It is necessary to choose a suitable type of controllers. Their location on the device is chosen with regard to their frequency of use and comfortable reading or control. Controls must simultaneously satisfy the operator and the operating force needed (Fig. 37).

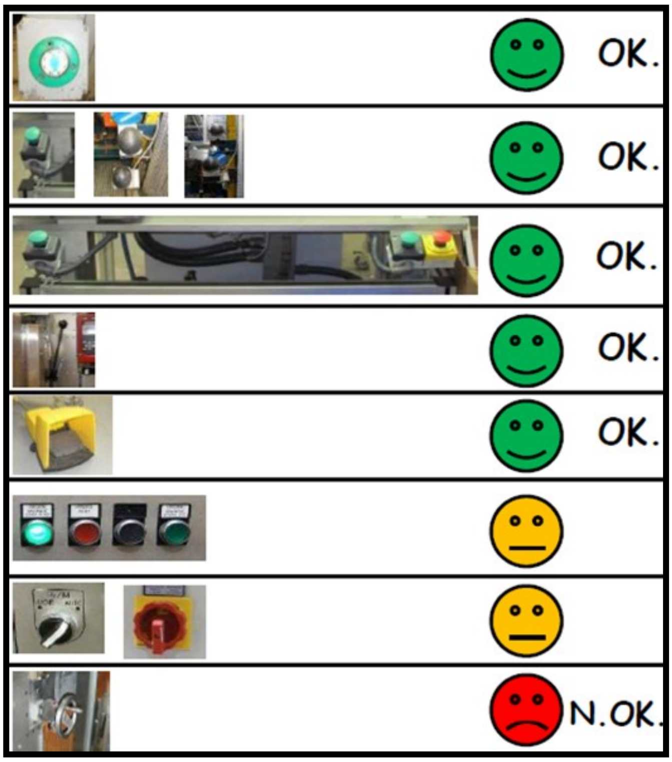


Fig. 37 Examples of controls [37]

On the (Fig. 37), is shown how the button should lool like to make sure that operatoro won't make any mistake during the work.

On the picture is devided to three colors as the traffic light. The explanations of those lights are:

- Green means it's clear for the operator where should he push to stop the machine in case of urgency.
- Yellow means that it's not the best case, because the operator can be confused by the number of buttons or by the look of the buttons to see if he's doing it right or not.
- Red, its unconrtable situation for the operator and it's forbidden to have it at the production.

As a constructer of tool, I recommend to use only the green propousals to make a start-stop button for the tool.

6. FMEA

The term FMEA (Failure Mode Effects Analysis), we mean a systematic set of activities that make it possible to prevent failures and save time and money spent on repairs. The purpose of the method is to identify the cause of errors and propose measures for its elimination. In practice FMEA divided into two types. The first type is a design and a second process. The new design was applied D-FMEA, which is focused exclusively on products it selv. It is especially useful in the design of new construction during product development. After manufacturing the product uses the process FMEA (P-FMEA), which aims to eliminate errors in the manufacturing process of the product and minimize the cost of repairs and maintenance. During the work achievement we will split the D-FMEA to two parts, which are: D- FMEA for a screw-driver and D-FMEA for product holder. Regarding decisions value to check if the value is conserned or not with need of new measurement. I will propose a limit measure value, which we present an example of scales:

- Less than 120 points => measures is not necessary.
- More than 120 points => proposed measures must be.

6.1. D-FMEA for product holder

In the analysis of the current process were evaluated using the release of pneumatic clamping cylinders, which can be caused by loosening or damage of fasteners. This disorder can cause product damage or destruction clamping prisms. It is therefore necessary to examine the connection. The proposed measures their risk value has fallen below the critical level.

For additional risk component was evaluated shaft that excessive load may cause damage to her store.

The most critical point of the product according to the FMEA is potential damage to the mooring line of air preparation equipment, which in addition to clamping carried out further positioning the product. In this case it is necessary to examine the reasonableness of the current routing of hoses to a product and as an additional measure in critical areas such lines fitted covers. Even after the possible introduction of a number of risk measures is in this case more than 80 points. The main reason is the fault detectability before its creation. Preparation of the fault will lose their function and the whole machine becomes inoperable. In the case of disorder is already easy to detect because of noise escaping pressure from the damaged hose. Table 10 shows the number FMEA for the product in Annex No. 9 (Tab. 9).

6.2. D-FMEA for screw-driver

In the screw-driver pointing device and the entire upper frame were dangerous places for disorders diagnosed screw connections on the linear positioning system at the point of attachment to the base frame and connection with a screw-driver. When the operation is suspicion of a possible loosening of bolted joints due to the operation of the equipment, and it has been suggested measures include the use of spring washers or you can use self-locking nuts in these exposed areas.

Furthermore, there has been diagnosed as risk suspension control panel on the swivel arm, which could potentially cause damage to the control panel and possible injury to the operator. Therefore, it is necessary to focus on Fasteners movable arm, so to prevent its release. In addition, there should be sufficient capacity dimensioning shoulders, mainly because of its overload of. This failure would cause the machine to malfunction and stop the entire line because of the absence přemontovaných subassemblies, which are pre-assembled on-line according to the requirements of subsequent work (FMEA analysis result is shown in Annex 10).

6.3. FMEA conclusion

After processing the complete D-FMEA for the product holder and screw-driver, which are listed in the Annex, has been found critical risk higher than 100 Therefore, it was not necessary to make any structural or technological remedy for the proposed facility. It will also be necessary to review the existing process FMEA for modified work. The aim of process FMEA is to find risks in the production process that is used to improve the prevention of errors in the production process. This analysis is not a part of this thesis, therefore not listed here will be addressed in the implementation stage equipment.

7. Evaluation of thesis goals

The main objectives of the thesis were to innovate the equipment for assembly of air conditioning canal. For sub-goals to achieve the main objective were also determined:

1. Design and upgrading workstations.
2. Increase productivity by at least 25%.
3. Reduce ergonomic stress at station.
4. Reduce cycle-time by 20%.
5. Implementation of automatic screwing on the workstation.

For achieving the above sub-goals were requesting the following tools and analytical methods:

6. Analysis of the exisiting tool situation.
7. Innovative opportunities and defining project goals.
8. Determination of technical specifications by using QFD method.
9. Proposals min. three solution concepts and systematic selection of the final concept.
10. New design of equipment components.
11. Design review using the D-FMEA.

To fulfill the thesis goal was requested to achieve all of the objectives and sub-objectives. All are demonstrated inside of work in individual chapters, but even with that I will make a simple analyze point by point to show that all points has been meted.

Point no. 1, has been treated in the chapiter no. 5 (Construction design). Where I introduced a new concept of the tool (please see chapter 5 and paragraph 3).

Point no. 2, there are a simple relationship between the productivity and takt time. The relationship is follow:

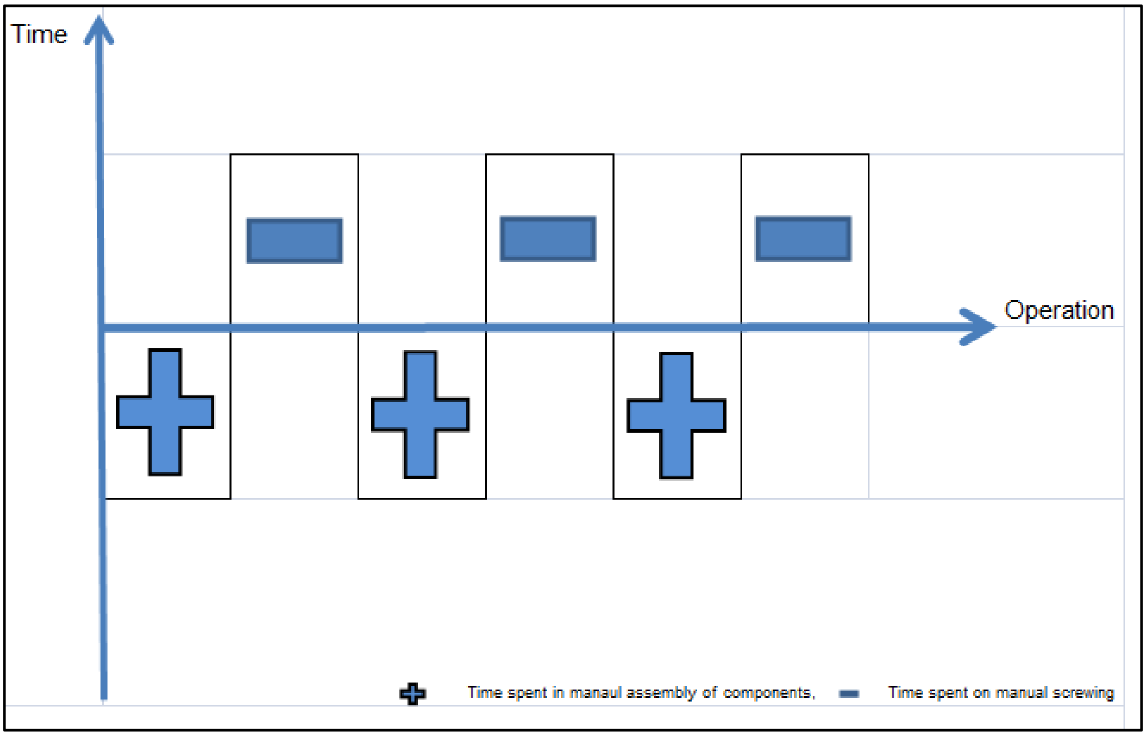
- Decreasing the working time of operator by tool => increasing productivity
- Increasing the working time of operator by tool => decrease the productivity.

By implementing the new tool concept we come up to decreasing the working time of operator and this bring to increasing productivity.

During the work in chapter 2 (paragraph 2.6) was discussed the needed time of work on the station. The measured result of the screwing operation is 27.72s, which represents almost 36% of the total time required to complete the operation manually. As already explained in the thesis, the assembly operation could be devided to two main assembly operations (manual assembly + manual screwing). The focus is to avoid the manual screwing because the manual assembly it not a topic of development due to high costs.

Graph no. 2 demonstrates how operator works at work stations. This simple graph shows:

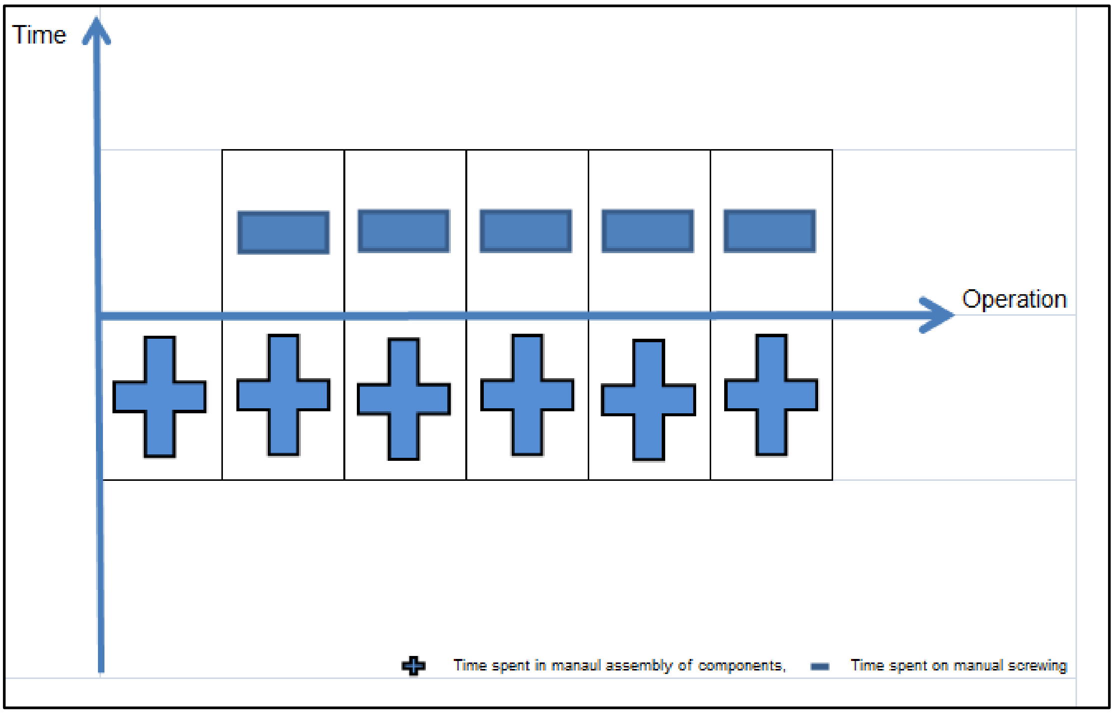
- Sign (+) represents the phase of manual assembly of components.
- Sign (-) represents the time spent manually for screwing phases.



Graph 2 Current operating status of the machine

This manual screwing time is completely unproductive. This means if we implement the auto-screwing we will save over 25% of the time spent on the operation and this will be the increasing of productivity requested by the thesis.

Graph no. 3 shows how the operation will be in future after implementing the auto-screwing.



Graph 3 Working status after implementing of auto-screwing

The operator at beginning of work shift starts manual assembly of parts into air canal. Than put those in the innovated tool and the tool start screwing automaticely. During auto-screwing the operator has almost over 25s to do other activities and he can start assembling the new air canal for the next step.

Point no. 3, reduce the ergonomic stress at the station. If the operator will have only to manual assembled and won't screw manually, this can be reducing the ergonomic stress at the station.

Point no. 4, if we use auto-screwing we already save 27s which is more than 20% of the cycle time.

Point no. 5, I consider this as a global request and it include the whole work thesis.

Point no. 6, analyze of existing tool situation, can be found under chapiter number 2. On which we discuss this point.

Point no. 7, is innovation opportunities and goals. It will dicussed and analyzed in the chapiter 2, and paragraph 2.10 .and 2.11.

Point no. 8, is QFD and technical specification. See chapiter no. 3.

Point no. 9, where I should introduce at least three solutions, I introduced five solutions. See chapiter number four.

Point no. 10, is a new design of equipment, it can be found in chapiter 5, paragraph 5.3.

And the point no. 11 requested a D-FMEA. This is also done in chapiter no. 6.

To fulfill the aims of this work were used in all of the required analytical methods and tools for innovation engineering (QFD, FMEA, morphological matrix, etc.).

The objective of the thesis, including all its sub-objectives was successfully met.

8. Economical evaluation and final conclusion

To compare the bringing values of this change I created a simple table with all information such as: actual situation, investment to make, real cost at market, saving and the pay back of the investment. More information could be found in (Tab. 9) below.

Tab. 9 Economical evaluation with bringing values of new concept [9]

Actual situation	Investment to make	Real cost of new tool	Saving	Pay back
▪ We produce 1016 pcs per day ▪ One operator cost BHER about 15.000,-€ per person per year ▪ Cost of 3 shifts are : 3 x 15.000,0€ = 45.000,-€ ▪ BEHR defined the maximum budget to invest is 45.000,-€	▪ Tool cost, maximum 45.000,-€ ▪ Time investment for change ▪Involvement of Team (Project management, Quality, Design ..)	▪ Cost of new tool (all included , design, assembly, set up ...), is about 31.500,-€ ▪ Lead time to have the new tool is about 4 months, including all	▪ We save already 13.500,-€, difference between budget and real cost ▪Reduce production cycle time per piece by 36% ▪Free operator capacity of 27s ▪ If operator per shift per year cost 15.000,-€ , this means that 36% is about 5.400,-€, almost one third of costs will be saved	▪ Implementing new tool will bring almost 5.400 x 3 =16.200,-€ saving per year ▪If we compare this to investment, it will be paid back in maximum 2 year. Project end of production is 2019. ▪Operator with free capacity of 27s can be used for other activities ▪Number of parts per day will increase by 36% per shift, instead of 1016 pcs per day, we will produce 1381 pcs ▪ Help other Czech companies to have business and new cooperation

After gothering all information from suppliers and market costs estimation, I found out that one of supplier can make whole work, this means, tool design, construction, implementing to existing process and follow until release with total cost of 31.500,- €. I I believe that we can find even better offer. But even if we consider those costs, it still below our target which is 45.000,-€.

By this I would like to confirm and recomond to Management of BEHR to implement the new tool concept due to all bringing values of the innovation.

9. List of literature

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Websites:

[1] www.behrgroup.com

[2] www.festo.com

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10. List of Pictures

11. Pictures property

[1] BEHR or MAHLE BEHR property, Web: www.behrgroup.com. Date 20.02.2014

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[16] BEHR or MAHLE BEHR property, Web: www.behrgroup.com. Date 20.02.2014

[17] Own property

[18] Own property

[19] Own property

[20] Own property

[21] Own property

[22] Own property

[23] Own property

[24] Own property

[25] Own property

[26] Used from screwing supplier, catalogue part date of 1.04.2014

[27] Used from screwing supplier, catalogue part date of 1.04.2014

[28] Own property

[29] Own property

[30] Own property

[31] Own property

[32] Own property

[33] Own property

[34] Own property

[35] Own property

[36] BEHR or MAHLE BEHR property, Web: www.behrgroup.com. Date 20.02.2014

[37] BEHR or MAHLE BEHR property, Web: www.behrgroup.com. Date 20.02.2014

12. List of tables

13. List of Charts

14. List of annexes

Annex 1: QFD screw-driver. Source: own work.

Annex 2: QFD for product. Source: own work.

Annex 3: Current status of the machine. Source: Existing drawings from the company Behr.

Annex 4: Future state machines. Source: own work.

Annex 5: Drawing of desk. Source: own work.

Appendix 6: Drawing shaft. Source: own work.

Annex 7: Drawing holder. Source: own work.

Appendix 8: Drawing table for the tuning screw feeder. Source: own work.

Annex 9: D-FMEA product. Source: own work.

Annex 10: D-FMEA screw-driver. Source: own work.

Annex 11: CD with diploma thesis saved in PDF.